PB-217 236

POLLUTIONAL EFFECTS OF PULP AND PAPER MILL WASTES IN PUGET SOUND

Federal Water Pollution Control Administration
Portland, Oregon

March 1967

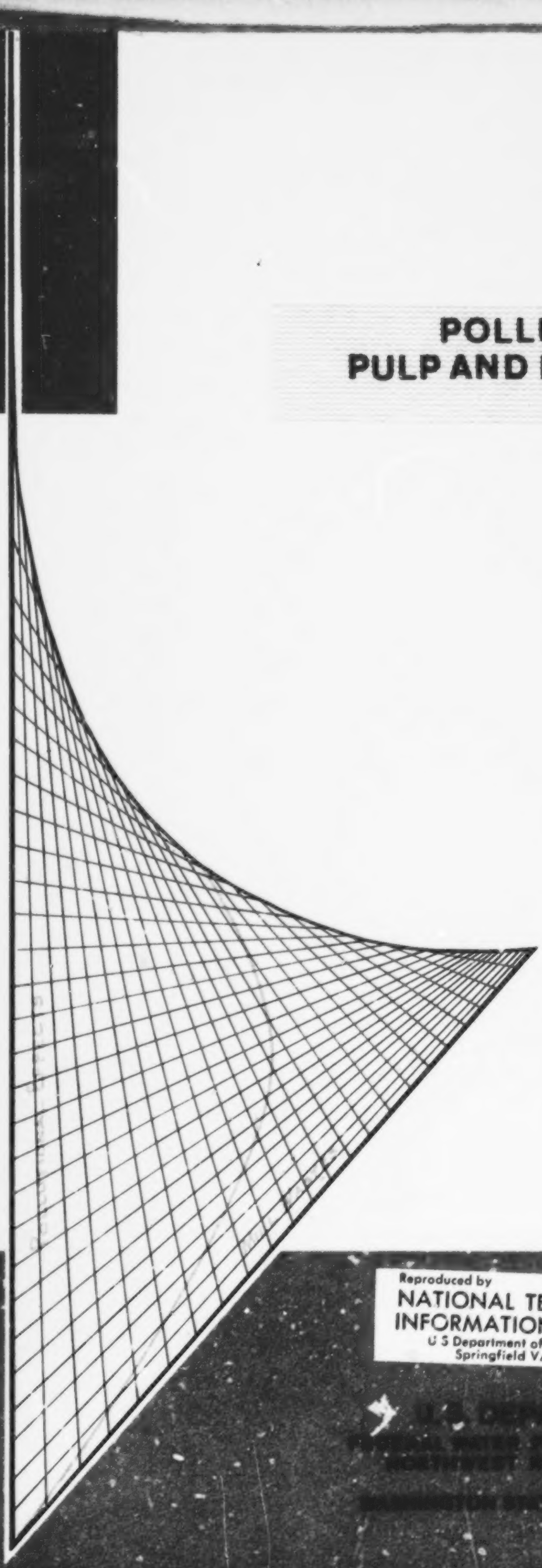
DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 217 236

POLLUTIONAL EFFECTS OF PULP AND PAPER MILL WASTES IN PUGET SOUND

MARCH, 1967



Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
NORTHWEST REGIONAL OFFICE, PORTLAND, OREGON
AND
WASHINGTON STATE POLLUTION CONTROL COMMISSION
OLYMPIA, WASHINGTON

DEPARTMENT OF THE INTERIOR

In its assigned function as the Nation's principal natural resource agency, the Department of the Interior bears a special obligation to assure that our expendable resources are conserved, that renewable resources are managed to produce optimum yields, and that all resources contribute their full measure to the progress, prosperity, and security of America, now and in the future.

POLLUTIONAL EFFECTS OF PULP AND PAPER MILL WASTES IN PUGET SOUND

A REPORT ON STUDIES CONDUCTED BY THE
WASHINGTON STATE ENFORCEMENT PROJECT

Details of illustrations in this
document may be better studied
on microfiche.

March 1967

U. S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
NORTHWEST REGIONAL OFFICE
PORTLAND, OREGON

WASHINGTON STATE POLLUTION CONTROL COMMISSION
OLYMPIA, WASHINGTON

I

TABLE OF CONTENTS

Page No.

FOREWORD i

SUMMARY AND RECOMMENDATIONS I

PART I - BACKGROUND

1. The Pollution Problem 1
2. General Study Area - Puget Sound 9
3. Water Uses 17
4. Waste Disposal 21

PART II - BELLINGHAM STUDIES

5. Introduction 25
6. Wastes 29
7. Waste Distribution and Water Quality 39
8. Juvenile Salmon 69
9. Bottom Organisms 95
10. Oysters 105
11. Oyster Larvae 131
12. Flatfish Eggs 157
13. Plankton 175
14. Periphyton 193
15. Bacterial Quality 201
16. Summary 205

TABLE OF CONTENTS (cont.)

Page No.

PART III - ANACORTES STUDIES

17. Introduction 211

18. Wastes 215

19. Waste Distribution and Water Quality 223

20. Oyster Larvae 233

21. Summary 239

PART IV - EVERETT STUDIES

22. Introduction 243

23. Wastes 249

24. Waste Distribution and Water Quality 269

25. Juvenile Salmon 303

26. Bottom Organisms 331

27. Oyster Larvae 347

28. Flatfish Eggs 361

29. Plankton 367

30. Bacterial Quality 377

31. Summary 381

PART V - PORT ANGELES STUDIES

32. Introduction 387

33. Wastes 391

TABLE OF CONTENTS (cont.)

Page No.

PART V - PORT ANGELES STUDIES (cont.)

34. Waste Distribution and Water Quality 403

35. Juvenile Salmon 425

36. Bottom Organisms 435

37. Oyster Larvae 441

38. Bacterial Quality 457

39. Summary 461

LITERATURE CITED 465

FOREWORD

This report presents the work and findings of the Washington State Enforcement Project, a joint Federal-State program investigating water pollution in Puget Sound. The Project is a cooperative study of the Washington State Pollution Control Commission and the Federal Water Pollution Control Administration, Department of the Interior. It was initiated on the recommendation of the enforcement conference held in Olympia, Washington, on January 16-17, 1962. This conference was convened under the authority of Section 8 of the Federal Water Pollution Control Act and for the purpose of considering the State of Washington's request for Federal assistance in abating pollution in Puget Sound. The proceedings and recommendations of the conference were published in three volumes of transcript (Anon., 1962a).

The Project conducted investigations in four parts of the Sound and is primarily concerned with the pollutional effects of wastes discharged by seven pulp and paper mills. These study areas and mills are:

Bellingham	Georgia-Pacific Corporation (formerly Puget Sound Pulp & Timber Company);
Anacortes	Scott Paper Company;
Everett	Scott Paper Company; Weyerhaeuser Company (sulfite pulp mill); Simpson Lee Paper Company;
Port Angeles	Fibreboard Paper Products Corporation; Rayonier Incorporated.

I

Each of these mills discharges untreated or partially treated process wastes into estuarine waters. The objectives of the Project were to determine the effects of these wastes on water quality and marine life, to delineate their interferences with legitimate water uses, and to ascertain pollution abatement needs. To accomplish these ends, the Project conducted an integrated and comprehensive study program of in-plant waste surveys, waste distribution and water quality studies, biological investigations, and economic studies. This study program was begun in April 1962 and was completed in June 1966.

There are several smaller industries not discussed in this report that discharge wastes into the study areas. These will be considered by the Washington State Pollution Control Commission when Water Quality Standards and associated implementation and enforcement plans are developed for all the waters of Puget Sound.

The points of major waste discharge in the four study areas are separated by considerable distances and physical features of land and water. Thus, the pollution incident to each is a distinct and individual situation. This report considers separately each of these areas and the studies conducted therein.

Only the summaries of data and information obtained are included in this report. The raw data on which these are based are contained in the files of the Federal Water Pollution Control Administration, Portland, Oregon and the Washington State Pollution Control Commission, Olympia, Washington. These data are available for inspection by all interested parties. Similarly, the technical details of the methods and procedures employed in many of the field and laboratory studies are described, by necessity, in brief terms. Persons interested in a fuller description of these techniques will be accommodated.

SUMMARY AND RECOMMENDATIONS

Summarized in this section are the major findings reached in the comprehensive studies that were conducted in each of the four study areas. These findings, and the resulting recommendations, are listed separately for each area in the same order discussed in the main body of the report.

VIII

BELLINGHAM STUDIES

SUMMARY

The Georgia-Pacific Corporation's pulp, board, and paper mill located on Whatcom Waterway at Bellingham is the principal source of wastes present in waters of the Bellingham study area. These wastes, discharged directly into Whatcom Waterway adjacent to the mill, are found dispersed in near-surface waters throughout the Bellingham-Samish Bay system and, on occasion, even in the Anacortes area.

Project studies have shown that waste levels present in the system are excessively damaging to the indigenous marine community. These damages are essentially of two specific types: (1) those of an acute nature, occurring mainly in Bellingham Harbor and associated with the concentrated sulfite waste liquors and settleable solids-bearing wastes discharged into Whatcom Waterway, and (2) those of a more chronic nature, occurring throughout the outer waters of the Bellingham-Samish Bay system and associated with dilute concentrations of sulfite waste liquors.

In Bellingham Harbor, waste discharge from the Georgia-Pacific mill results in high waste concentrations, sludge deposits, and attendant water quality degradation. These conditions are incompatible with marine life and interfere with other legitimate water uses. Specifically, the wastes have been shown to:

1. Be injurious to juvenile salmon, resulting in extensive damage to the salmon fishery while juveniles are migrating

through the Harbor area.

2. Suppress phytoplankton activity within the Harbor.
3. Contain settleable waste solids that form sludge deposits in Bellingham Harbor; these deposits damage bottom organisms and produce harmful water quality degradation, as well as cause general aesthetically unattractive conditions.

It is imperative that all wastes discharged from the Georgia-Pacific pulp, board, and paper mill be treated for removal of settleable solids, and that the point of waste discharge be removed from the confines of Whatcom Waterway.

Of even greater importance to the marine communities of the study area are the concentrations of sulfite waste liquor found dispersed throughout the surface waters of Bellingham and Samish Bays. These wastes, even in relatively dilute concentrations (5 to 15 ppm SWL), are damaging to immature forms of indigenous fish and shellfish, with such damages generally decreasing with distance from the Georgia-Pacific mill complex. Specifically, Project studies have shown that such wastes:

1. Damage oyster larva throughout the study area, with excessive damage produced in northern Bellingham Bay.
2. Cause some adult and juvenile oyster mortality, particularly in Bellingham Bay, and, more importantly, adversely affect oyster growth and market condition throughout the study area.
3. Damage English sole eggs which are seasonally present in surface waters throughout the study area. Extensive damage would be expected at waste levels found in northern

Bellingham Bay, with lesser damages expected in the remainder of the Bellingham-Samish Bay system.

English sole eggs and Pacific oyster larva are two forms studied intensively by the Project, but which represent a large group of marine organisms expected to be similarly affected by Georgia-Pacific wastes. This group includes some 10 species of sole, 6 species of cod, anchovy, herring, smelt, 3 species of clams, and crabs, to mention some of the more important.

The physical characteristics of the Bellingham-Samish Bay system severely limit its ability to assimilate waste products. To prevent additional damages to these important marine resources it is, therefore, necessary that sulfite waste liquors discharged by Georgia-Pacific mill be reduced significantly at the source. Minimum protection of these organisms during their most sensitive life stages requires that SWL concentrations in the surface 50 feet of depth not exceed 10 ppm beyond the initial waste dispersion zone. The initial waste dispersion zone is defined as that area of Bellingham Bay north of an east-west line (magnetic) extending from Post Point to Lummi Peninsula.

Discharge of raw and partially treated domestic wastes from the City of Bellingham results in bacterial concentrations in the Bellingham Harbor hazardous to human health.

Stokely-Van Camp and Bumble Bee Seafoods also discharge solids-bearing wastes into Bellingham Harbor which contribute to the formation of sludge deposits.

RECOMMENDATIONS

To provide abatement of pollution occurring in Bellingham Harbor and throughout the Bellingham-Samish Bay system, it is recommended that:

A. Georgia-Pacific Pulp, Board, and Paper Mill

1. Provide primary treatment of all solids-bearing wastes to provide for (a) removal of all settleable solids and (b) 70% removal of volatile suspended solids.
2. Provide for a reduction in the discharge of sulfite waste liquor solids by that degree necessary to achieve the recommended levels of water quality in the Bellingham study area (maximum of 10 ppm SWL in the surface 50 feet of depth beyond the initial waste dispersion zone).
3. Construct a submarine outfall equipped with an adequate diffuser to permit discharge of all residual wastes outside the confines of Whatcom Waterway into a depth of not less than 25 feet (measured at MLLW).
4. Remove, by dredging, the existing accumulation of sludge in the Harbor and dispose of such material on land.
5. Modify chip-barge unloading operations to eliminate spillage of wood chips.

B. Stokely-Van Camp and Bumble Bee Seafoods

1. Provide facilities to discharge all wastes to the City

of Bellingham sewer system for treatment at the City's sewage treatment plant.

C. City of Bellingham

1. Provide for collection of wastes discharged by the Fairhaven sewer and other unintercepted discharges.

2. Provide secondary treatment and effluent chlorination at the present primary plant site with effluent discharge beyond the confines of Whatcom Waterway into a depth of not less than 25 feet (measured at MLLW).

ANACORTES STUDIES

SUMMARY

The Scott Paper Company pulp mill located in Anacortes is the major source of wastes now discharged to Guemes Channel. Pulping wastes are pumped to the Channel from the mill site located on Padilla Bay. The tidal currents in Guemes Channel provide conditions which are well suited to assimilate residual waste discharges. However, pulping wastes discharged by the Scott Paper Company mill do adversely affect water quality in the immediate waste dispersion zone. This effect can be significantly reduced by extending the outfall and diffuser section to a greater depth, thereby providing greater initial dilution. Settleable solids materials in the waste discharge probably do not settle in the immediate discharge zone but are carried to outer channel limits and deposited. Nevertheless removal of these materials is considered a prerequisite prior to discharge to coastal waters.

Fish processing wastes are discharged into Guemes Channel by Fishermen's Packing Corp. and Sebastian Stuart Fish Co. on a seasonal basis. The wastes discharged contain significant quantities of settleable solids.

Domestic wastes from the City of Anacortes receive primary treatment plus chlorination prior to discharge to Guemes Channel.

RECOMMENDATIONS

To provide abatement of pollution now occurring in Guemes Channel and to better utilize the Channel's waste dispersal properties, the following is recommended:

A. Scott Paper Company

1. Provide primary treatment of all solids-bearing wastes to provide for (a) removal of all settleable solids and (b) 70% removal of volatile suspended solids.

2. Extend the present waste outfall line, equipped with an adequate diffuser section, into Guemes Channel to a depth of not less than 50 feet (MLLW).

3. Provide necessary additional pumping and/or discharge facilities to insure that no bypassing of wastes to Padilla Bay will occur.

B. Sebastian Stuart Fish Co.

1. Provide facilities to discharge all wastes to the City of Anacortes sewer system for treatment at the City's sewage treatment plant.

EVERETT STUDIES

SUMMARY

The principal sources of wastes discharged to the Everett Harbor and Port Gardner are the Weyerhaeuser Company sulfite pulp mill and the Scott Paper Company pulp and paper mill located in Everett. Concentrated pulping wastes from these two operations are discharged through a deep-water outfall to Port Gardner, while large volumes of log-barking, pulp-washing, bleaching, and paper-making wastes are discharged to Everett Harbor immediately adjacent to the two mills. A portion of these latter wastes receive primary treatment prior to discharge.

Project studies have shown that damages resulting from these discharges are essentially of two types: (1) those associated with or caused by the discharge of large volumes of solids-bearing wastes to Everett Harbor adjacent to the Scott Paper Company and Weyerhaeuser Company mills, on occasion containing concentrations of toxic chemicals; and (2) those resulting from the toxic effects of the sulfite waste liquors when diluted and dispersed throughout the surface waters of Port Gardner, Possession Sound, Port Susan, and Saratoga Passage.

In Everett Harbor, discharges from Scott Paper Company and the Weyerhaeuser Company sulfite mill result in high waste concentrations, sludge deposits, and attendant water quality degradation. These conditions are incompatible with marine life and interfere with other legitimate water uses. These wastes have been shown to:

1. Cause injury or mortality to juvenile salmon migrating through Everett Harbor.
2. Cause extensive bottom sludge deposits which produce toxic concentrations of sulfides in the adjacent waters that are damaging to fish and bottom organisms and result in overall aesthetically unattractive conditions.
3. Suppress phytoplankton activity in the Everett Harbor area.

Abatement of these damages can be accomplished by providing for removal of all settleable solids from the wastes and removing the point of waste discharge from the confines of Everett Harbor.

The concentrations of sulfite waste liquor found in the surface waters throughout the study area present an even greater threat to marine communities indigenous to the area. As in the Bellingham-Samish Bay system, these wastes in dilute concentrations, 5-15 ppm SWL, have been shown to be damaging to larval forms of fish and shellfish found in the study area. English sole eggs and Pacific oyster larvae are two of the forms with which the Project has worked intensively but which represent a large group of marine organisms expected to be similarly affected. These include some 10 species of sole, 6 species of cod, 3 species of clams, and anchovy, herring, smelt, and crabs to mention a few of the more important.

Project studies have shown that such wastes:

1. Produce damages to developing English sole eggs found throughout the surface waters of Port Gardner and Everett Harbor. Extensive damage or mortality would be expected in and adjacent to Everett Harbor, with the

degree of damage decreasing at increasing distances from the waste source.

2. Produce extensive damage to oyster larvae. Similar damages would be expected to occur to other indigenous shellfish, as indicated by damages to the sessile intertidal organisms.

To prevent additional damages and provide minimum protection of these organisms during their most sensitive life stages, it is required that SWL concentrations in the surface 50 feet of depth not exceed 10 ppm beyond the initial waste dispersion zone. The initial waste dispersion zone is defined as that area of Everett Harbor and Port Gardner within a 1.5 mile radius of the southwestern tip of the peninsula bordering Everett Harbor.

Although the strong pulping wastes disposed by the Scott and Weyerhaeuser mills through the deep-water outfall produce relatively high SWL concentrations throughout the deep waters of the Everett area, the results of biological studies do not demonstrate that they presently cause any measurable damage to marine life inhabiting the deeper waters. Admittedly, these biological studies primarily treated marine forms that inhabit surface water. Review of presently available literature and considered judgment, however, have not produced any available evidence of damage or injury sustained by the marine life which populates the deep waters of the Everett area and which would be affected by the deep-water diffuser wastes. There remains some likelihood, though, that these wastes may, in diffusing upward, contribute to the surface SWL concentrations in the outer limits of the study area. It is not possible to determine to what extent this may occur.

Wastes from the Simpson Lee Company sulfate pulp mill are discharged into the Snohomish River some 10 miles upstream from its mouth. This mill is relatively small but does discharge significant quantities of settleable solids materials that contribute to the extensive bottom sludge deposits adjacent to the mouth of the Snohomish River.

The City of Everett's domestic wastes are treated in a waste stabilization pond and then discharged into the Snohomish River at a point 3.5 miles upstream from its mouth. Bacteriological studies in the River have shown that bacterial concentrations now approach, and at times exceed, those levels recommended by the Washington State Pollution Control Commission. Intermittently high bacterial counts were also noted in and adjacent to the Everett Harbor.

RECOMMENDATIONS

To provide abatement of pollution occurring in Everett Harbor and throughout the Port Gardner system, as outlined above, it is recommended that:

A. Scott Paper Company

1. Provide primary treatment of all solids-bearing wastes to provide for (a) removal of all settleable solids and (b) 70% removal of volatile suspended solids.
2. Provide for a reduction in the sulfite waste liquor solids discharged to and found in the surface waters of the study area. These reductions should be sufficient to achieve the recommended levels of waste quality

(maximum of 10 ppm SWL in the surface 50 feet of depth beyond the initial waste dispersion zone).

3. Construct a submarine outfall equipped with an adequate diffuser to permit discharge of all residual wastes outside the Everett Harbor.
4. Remove, by dredging, the existing accumulation of sludge in the Harbor and dispose of such material on land.
5. Modify chip-barge unloading operations to eliminate all spillage of wood chips.

B. Weyerhaeuser Company Sulfite Mill

1. Provide primary treatment of all solids-bearing wastes to provide for (a) removal of all settleable solids and (b) 70% removal of volatile suspended solids.
2. Provide for a reduction in the sulfite waste liquor solids discharged to and found in the surface waters of the study area. These reductions should be sufficient to achieve the recommended levels of waste quality (maximum of 10 ppm SWL in the surface 50 feet of depth beyond the initial dispersion zone).
3. Construct a submarine outfall equipped with an adequate diffuser to permit discharge of all residual wastes outside the Everett Harbor.
4. Remove, by dredging, the existing accumulation of sludge in the Harbor and dispose of such material on land.

5. Modify chip-barge unloading operations to eliminate all spillage of wood chips.

C. Simpson Lee Company

1. Provide primary treatment of all solids-bearing wastes to provide for (a) removal of all settleable solids and (b) 70% removal of volatile suspended solids.

D. City of Everett

1. Washington Pollution Control Commission conduct additions bacteriological studies to determine when chlorination of the City of Everett's waste stabilization pond effluent will be required.

PORT ANGELES STUDIES

SUMMARY

There are two principal sources of pulp mill wastes in the Port Angeles area; the Fibreboard Paper Products Corp. pulp and board mill located on the south shore at the inner end of Port Angeles Harbor, and the Rayonier Incorporated pulp mill located on the south shore at the Harbor entrance. Both mills discharge process wastes directly to Harbor surface waters. Of the two mills, Rayonier Incorporated is by far the more significant waste source, contributing about 92 percent of the combined discharges of SWL, COD, BOD_5, and total solids. Wastes from these mills are found throughout Port Angeles Harbor, particularly in the southern portion, and eastward nearshore as far as Dungeness Spit, some 12 miles from the Harbor entrance.

The Crown Zellerbach Corp. pulp (mechanical) and paper products mill, located at the inner end of the Harbor, discharges its wastes directly to the Strait of Juan de Fuca. Except for some transient local collection near the outfall these wastes generally are dispersed seaward by Strait currents and, thus, are not prominent within the main Port Angeles study area. However, during past years the now-discontinued Crown Zellerbach discharge of high solids wastes into Port Angeles Harbor substantially contributed to a large sludge bed still present at the inner end of the Harbor.

Project studies have shown that these wastes are damaging to marine life in the Port Angeles study area. The damages are of two types: (1) acute damages, occurring within the Harbor adjacent to each mill and mainly associated with the concentrated sulfite waste liquors and settleable solids in the mill effluents, and (2) chronic damages, occurring throughout the study area and associated with dilute concentrations of sulfite waste liquors.

Within Port Angeles Harbor, waste discharges from Fibreboard and Rayonier produce high waste concentrations, sludge deposits and attendant water quality degradation surrounding each mill. Also, the sludge deposit formed by past Crown Zellerbach discharges continues to seriously degrade water quality adjacent to that mill. These conditions are incompatible with marine life and interfere with other legitimate water uses. Specifically, mill wastes discharged into the Harbor have been shown to:

1. Injure juvenile salmon migrating through the Harbor.
2. Form sludge deposits which damage benthic organisms, produce harmful water quality degradation, and result in general aesthetically unattractive conditions.

It is imperative that wastes from all three mills be treated for removal of settleable solids prior to discharge.

Of even greater importance to marine life in the study area is the presence of dilute sulfite waste liquor (from Fibreboard and Rayonier mills) in waters throughout the Port Angeles study area. Such wastes, even in concentrations as low as 5 to 15 ppm, have been found harmful to immature forms of fish and shellfish. Project bioassay studies in the Port Angeles area show that extensive damages occur to oyster larva at waste levels found in surface waters of the Harbor and eastward alongshore to Dungeness Spit. On the basis of other bioassay studies reported for Bellingham and Everett (Parts I and III, this report), these waste levels also are damaging to a wide variety of important marine life found in the affected portion of the Port Angeles study area, including crabs, clams, sole, cod, anchovy, herring and smelt.

The waste assimilation capacity of the Port Angeles study area is seriously limited by the presence of a large, slow moving, predominantly anti-clockwise, eddy circulation of water between Port Angeles Harbor and Dungeness Spit. This eddy tends to confine Fibreboard and Rayonier mill wastes to shallower waters alongshore before eventually dispersing them to the Strait of Juan de Fuca. This results in harmful concentrations of SWL throughout the eddy. Inadequate depth precludes relocation of the mill outfalls (to any reasonable site) within the eddy system to secure acceptable waste dilution. This is particularly true of the Rayonier mill because of its large volume of waste discharge. Therefore, to prevent further damage to the marine resources of the Port Angeles study area, it will be necessary to significantly reduce sulfite waste liquors at the source. Minimum protection of the marine biota during their most sensitive life stages requires that sulfite waste liquor concentration not exceed 10 ppm within 50 feet of the surface depth beyond an initial waste dispersion zone. The initial waste dispersion zone is defined as the area within Port Angeles Harbor bounded on the east by an arc formed by that radius originating from Rayonier Incorporated and extending to the eastward end of Ediz Hook, swung to the east.

The Pen-Ply plywood mill discharges a small amount of glue wastes to the Harbor, but no significant adverse effects on water quality were observed.

The City of Port Angeles discharges all of its domestic wastes untreated into Port Angeles Harbor. As a result, more than two miles of the City's waterfront is bacterially contaminated for water-contact use. Also, this waste source contributes substantial BOD and settleable solids loading to the Harbor. Protection of those persons engaged in contact use of these waters requires immediate abatement of this pollution.

RECOMMENDATIONS

To provide abatement of pollution presently occurring in Port Angeles Harbor and the surrounding study area, it is recommended that:

A. Rayonier Incorporated

1. Provide primary treatment of all solids-bearing wastes to provide for (a) removal of all settleable solids and (b) 70% removal of volatile suspended solids.
2. Provide for a reduction in the discharge of sulfite waste liquor solids by that degree necessary to achieve the recommended levels of water quality in the Port Angeles study area (maximum of 10 ppm SWL in the surface 50 feet of depth beyond the initial waste dispersion zone).
3. Construct a submarine outfall equipped with an adequate diffuser to permit discharge of all residual

wastes to a depth of not less than 50 feet (measured at MLLW).

4. Remove, by dredging, the existing accumulation of sludge adjacent to the point of waste discharge and dispose of such material on land.

B. Fibreboard Paper Products Corp.

1. Provide primary treatment of all solids-bearing wastes to provide for (a) removal of all settleable solids and (b) 70% removal of volatile suspended solids.

2. Construct a submarine outfall equipped with an adequate diffuser to permit discharge of all residual wastes to a depth of not less than 50 feet (measured at MLLW).

3. Remove, by dredging, the existing accumulation of sludge in the harbor adjacent to the point of waste discharge and dispose of such material on land.

C. Crown Zellerbach Corp.

1. Provide primary treatment of all solids-bearing wastes to provide for (a) removal of all settleable solids and (b) 70% removal of volatile suspended solids.

2. Construct a submarine outfall to permit discharge of all residual wastes to a depth of not less than 30 feet (measured at MLLW) in the Strait of Juan de Fuca.

3. Remove, by dredging, the existing accumulation of sludge adjacent to the mill in Port Angeles Harbor and dispose of such material on land.

D. City of Port Angeles

1. Provide for the collection of all domestic wastes discharges and treatment of these wastes by one of the two following alternate methods:

   Alternate 1. Provide primary treatment and effluent chlorination with discharge through a deep diffuser outfall.

   Alternate 2. Provide for secondary treatment and effluent chlorination with final disposal through a submerged outfall extending at least beyond the waterfront pier-head line.

Part 1

BACKGROUND

1. THE POLLUTION PROBLEM

The seven pulp and paper mills considered in this report discharge large quantities of process wastes into estuarine waters in four areas of Puget Sound. The characteristics of these wastes give rise to four types of water pollution. First and of greatest concern is the toxic effects of pulping wastes on marine life of the receiving waters. These wastes are found in high concentrations in the vicinity of discharge; therefore, problems of acute toxicity occur. After dispersion, in the outer-bay waters, these wastes are found in lesser concentrations; therefore, problems of acute or chronic toxicity to sensitive marine organisms appear. Second is the problem of additional disturbance of water quality in the vicinity of discharge; *viz*., conditions of reduced dissolved oxygen concentrations, lowered pH values, and introduced concentrations of other toxic substances. Individually or in combination, these conditions have a debilitating or damaging effect on the marine life inhabiting or otherwise utilizing the affected waters. Third is the problem of sludge deposits formed by settled waste solids. Such deposits are commonly found in the vicinity of waste discharge, and they are usually anaerobic hence, they produce toxic and odorous gases. These deposits have a deleterious effect on bottom-dwelling organisms. Last is the problem of aesthetic impairment of water quality by colored, odorous, and turbid mill wastes. Coloration and turbidity also reduce light penetration through the surface waters and thereby inhibit phytoplankton productivity.

THE PULP MILLS

Six of the mills considered herein are sulfite mills which employ acid, calcium or ammonium base cooking liquors to free wood fibers from other constituents of wood in the production of pulp. The seventh mill is a sulfate (kraft) mill which utilizes alkaline cooking liquors for the same purpose. Four of the mills have paper or board operations to convert pulp into finished products. Other processes employed by one or more of these mills include mechanical or hydraulic barking, wood chipping, groundwood pulping, and pulp bleaching.

Although differences exist among the exact manufacturing processes employed by individual mills, similar basic steps are followed by all. These are illustrated in Figure 1-1. On the left side of this figure appear the raw materials that enter the various processes; the progressiv manufacturing steps are shown; and on the right side appear the types of wastes produced in each of these steps.

Considering the manufacturing processes, wood is first debarked and reduced to chips. These chips go to the digester where they are cooked with appropriate chemicals to free wood fibers from the wood--the non-fiber constituents being dissolved. (Several digestion processes are in common use throughout the industry; Figure 1-1, however, considers only two--the sulfite process and the sulfate or kraft process.) The raw pulp from the digester is then washed and screened to remove cooking chemicals, dissolved wood impurities, and rejects. The unbleached pulp from this step is then bleached--in many cases--for the further extraction of impurities. Bleached pulp is dried and baled for shipment or transferred to the paper or board mill for conversion into finished paper products.

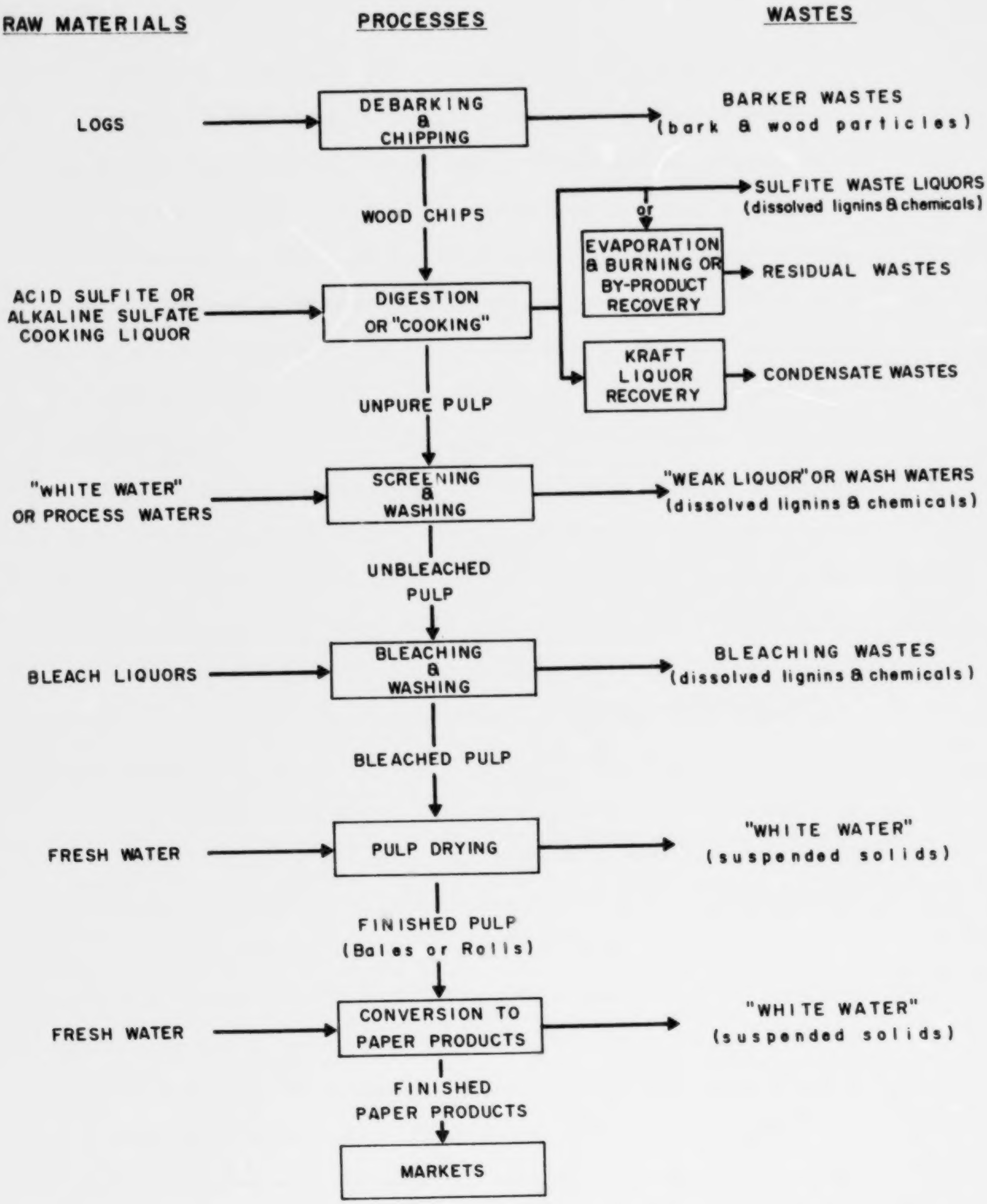

RAW MATERIALS
PROCESSES
WASTES
LOGS
DEBARKING & CHIPPING
BARKER WASTES (bark & wood particles)
WOOD CHIPS
SULFITE WASTE LIQUORS (dissolved lignins & chemicals)
or
EVAPORATION & BURNING OR BY-PRODUCT RECOVERY
RESIDUAL WASTES
ACID SULFITE OR ALKALINE SULFATE COOKING LIQUOR
DIGESTION OR "COOKING"
KRAFT LIQUOR RECOVERY
CONDENSATE WASTES
UNPURE PULP
"WHITE WATER" OR PROCESS WATERS
SCREENING & WASHING
"WEAK LIQUOR" OR WASH WATERS (dissolved lignins & chemicals)
UNBLEACHED PULP
BLEACH LIQUORS
BLEACHING & WASHING
BLEACHING WASTES (dissolved lignins & chemicals)
BLEACHED PULP
FRESH WATER
PULP DRYING
"WHITE WATER" (suspended solids)
FINISHED PULP (Bales or Rolls)
FRESH WATER
CONVERSION TO PAPER PRODUCTS
"WHITE WATER" (suspended solids)
FINISHED PAPER PRODUCTS
MARKETS

FIGURE 1-1. Simplified schematic of pulp and paper processing.

On the right side of Figure 1-1, additional boxed processes are shown for wastes from the cooking or digestion process. From sulfite mills, sulfite waste liquor is usually discharged into surface waters or disposed in some manner on the land. (Five of the sulfite mills considered herein discharge this liquor into surface waters.) This waste, however, can be processed or treated to recover cooking chemicals, heat, or by-products (upper box). Evaporation and burning, sometimes in tandem with fermentation for alcohol production (as partially practiced at one of the sulfite mills), is usually involved. Sugars--thus immediate biochemical oxygen demand--and total solids--lignin compounds--are removed, and the residual wastes produced have less pollutional impact. At sulfate mills, it is normal to evaporate and burn kraft waste liquors for the recovery of cooking chemicals (lower box). Biochemical oxygen demand and dissolved solids are reduced and condensate wastes are generated.

The most important feature of Figure 1-1 is the delineation of the types of wastes generated. Barker wastes and whitewaters from pulp drying and paper conversion (hereafter referred to as barker wastes and paper mill wastes) carry high concentrations of suspended solids, and this is their important pollutional characteristic. Settleable suspended solids in these wastes cause formation of sludge deposits, and truly suspended solids create turbidity and reduce light penetration in the receiving waters. In most cases, in spite of in-plant recovery facilities--save-alls for fiber recovery and screens for bark and wood chip recovery--these wastes carry suspended solids loads that could be substantially reduced by provision of adequate sedimentation facilities.

The other wastes--sulfite waste liquors (from the sulfite process without recovery), weak liquors, and bleaching wastes--are, collectively, pulping wastes. They are either discharged as combined wastes or are rapidly mixed in the receiving waters after discharge; therefore, in this report, they are treated singularly as pulping wastes. The pollutional characteristics of pulping wastes are (1) their high biochemical oxygen demand, (2) their toxicity, and (3) their color. They do carry some suspended solids but in much lesser amounts than barker and paper mill wastes. Sulfite waste liquor (SWL) is emitted in strong concentration from the digesters or blow pits and in dilute concentrations in the weak liquors from subsequent pulp washings. SWL is a heterogeneous mixture of inorganic and organic constituents; viz., spent cooking chemicals and dissolved, non-cellulose components of the raw wood (lignins, sugars, etc.) not usable for making paper products. The dissolved sugars and other readily-oxidized constituents give SWL an immediate oxygen demand which is measured as a 5-day biochemical oxygen demand (BOD_5). The dissolved lignins decompose very slowly; therefore, do not exert an appreciable BOD_5. This stability of the lignin constituents provides a means of measuring SWL concentrations--by the Pearl-Benson test, discussed later. SWL, in various dilute concentrations, has a toxic effect on various organisms, but the exact constituents responsible for this toxicity are not well known. Consequently, throughout this report, SWL will be treated as a toxic agent with the understanding that unknown components thereof are the inimical agents. Bleaching wastes augment the pollutional effects of sulfite waste liquor. The bleaching step is a further purification of the cellulose fibers of pulp. Accordingly, spent bleaching chemicals and dissolved, non-cellulose materials are constituents.

STUDY PROGRAM

In each of the four study areas, a comprehensive study program of three interrelated elements was conducted. Each program consisted of (1) in-plant wastes surveys to determine the amounts and characteristics of wastes discharged by the pulp and paper mills of consideration and by other major waste sources in the respective area, (2) waste distribution and water quality studies to determine the transport and dispersion of mill wastes in the receiving waters and to assess their effects on water quality, and (3) various biological studies to determine the effects of dispersed wastes and degraded water quality on the marine life of the area. These individual studies are described in the appropriate following sections.

Measurement of SWL. One aspect common to all studies was the measurement of SWL concentrations. Because sulfite waste liquor is the principal component of sulfite pulping wastes and because lignin, the constituent by which SWL concentration is measured, is relatively stable and not rapidly decomposed by biological action, SWL concentrations were employed (1) to measure the relative strength of pulping waste at the point of discharge, (2) to measure the relative concentrations of pulping wastes in the receiving waters and thereby trace the transport and dispersion of these wastes after discharge, and (3) to measure the relative concentrations of pulping wastes causing detrimental effects on various organisms studied *in situ* or in bioassay tests.

SWL concentrations were determined by the Pearl-Benson test (Barnes, et.al; 1963). Briefly, this test measures, spectrophotometrically, the relative concentrations of the lignin sulfonates of SWL, referenced against a standard, calcium-base, 10% solids SWL solution. Accordingly, SWL values, as presented in this report, are concentrations in parts per million (ppm) by volume of a solution containing 10% dry liquor solids by weight.

It is well known that the Pearl-Benson test also measures phenolic materials and certain other substances commonly found in natural drainage, domestic sewage, tanning wastes, kraft mill wastes and wastes for various other sources. Such "apparent SWL" concentrations can interfere with the use of the test for those purposes described above. That this interference is small and insignificant in the areas studied, however, is demonstrated by results from the following investigations.

1. Background concentrations of SWL were collected from tributaries discharging into each study area, from parts of each area distant from the waste sources, and from all parts of each area during periods when the sulfite pulp and paper mills were closed either for a holiday or because of a labor dispute. Background SWL concentrations were found to be always less than 5 ppm and frequently less than 3 ppm. Undoubtedly, these apparent SWL concentrations derived from naturally-occurring materials originating in land drainage or from non-sulfite pulping waste sources.

2. SWL concentrations in the waste streams from sulfite pulp and paper mills in each area were measured, and apparent SWL concentrations in the waste streams from major, non-sulfite-pulping waste sources in each area were measured. From calculated total daily loads of SWL and apparent SWL based on these data and flow information, it was determined that the total discharge of apparent SWL from non-sulfite-pulping sources was no greater than 3% of the total SWL discharge from sulfite pulping sources in any of the study areas. Consequently, SWL concentrations measured in the receiving waters must derive, principally, from sulfite mill waste discharges.

Accordingly, throughout this report, SWL concentrations greater than 5 ppm in the study area waters are taken as measurements of dispersed sulfite pulping wastes.

2. GENERAL STUDY AREA - PUGET SOUND

The general study area, Figure 2-1, includes the Strait of Juan de Fuca, the Strait of Georgia, and the inland waters of Puget Sound. Figure 2-1 also locates the four study areas: Bellingham, Anacortes, Everett, and Port Angeles.

LOCATION AND PHYSICAL FEATURES

The Puget Sound Basin occupies the northwest corner of the State of Washington and extends into the southwest corner of British Columbia, Canada. It covers an area of 3,600 square miles and is bounded on the west by the mountains of the Olympic Peninsula, on the northwest by the mountains of Vancouver Island, and on the east by the Cascade Mountains. At its northern end it opens to the coastal waters of Canada through the Strait of Georgia, and at its southern extremity it becomes a part of the Puget Sound-Willamette trough, which extends southward through Washington and into Oregon.

Puget Sound itself is a huge, glacially-formed estuary. It receives freshwater inflows from numerous tributary streams and is connected with the Pacific Ocean by the Straits of Georgia and Juan de Fuca. Although a single body of water, it is extensively fragmented into numerous bays, inlets, and channels. Its main channels are steep-sided with depths normally ranging from 300 to 600 feet, but reaching maximums of about 900 feet in some locations. Its bays and inlets are usually much more shallow, and many contain extensive delta areas formed at the mouths of tributary rivers.

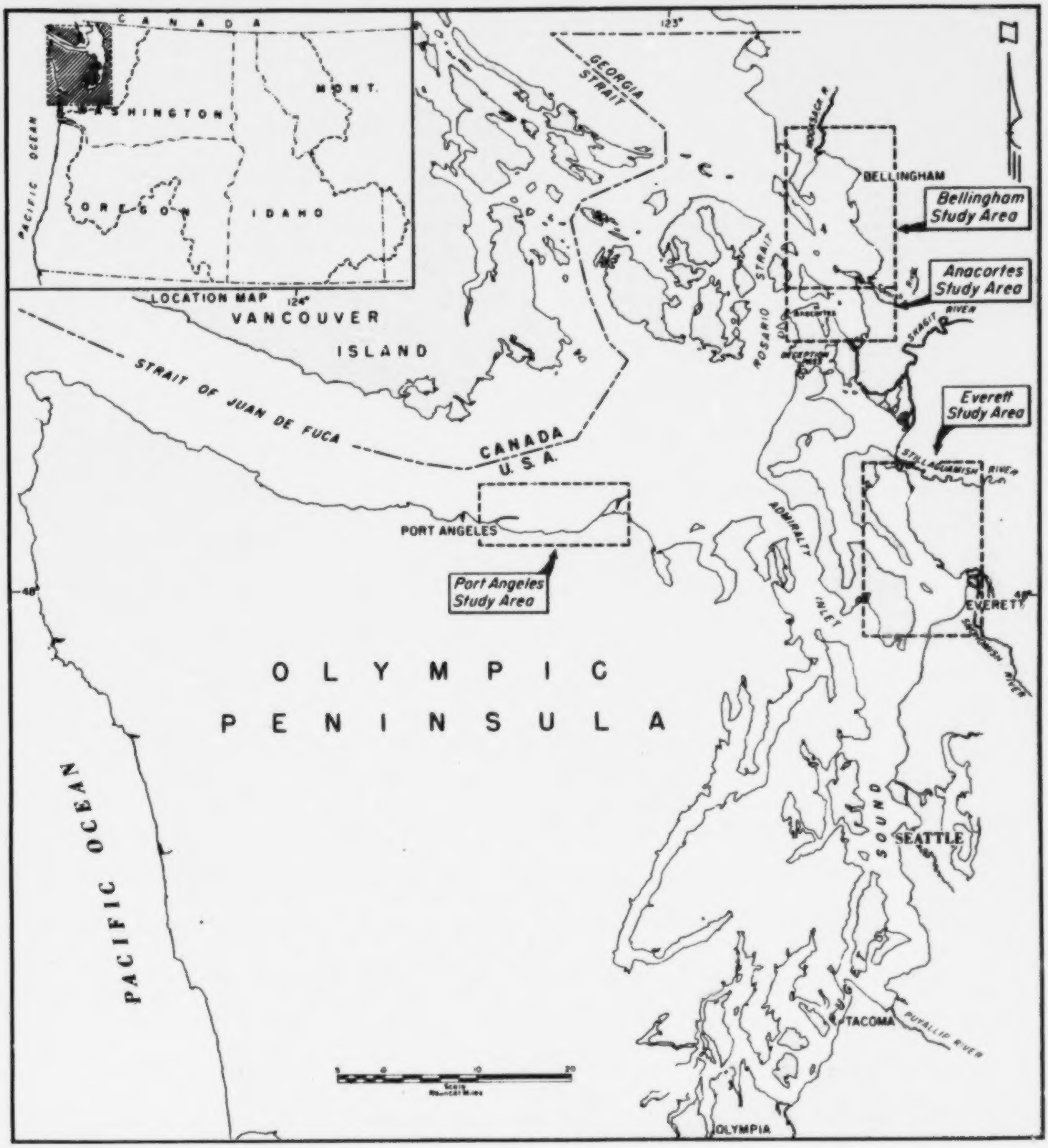

CANADA
WASHINGTON
MONT.
OREGON
IDAHO
PACIFIC OCEAN
LOCATION MAP
124°
123°
GEORGIA STRAIT
NOOKSACK R.
BELLINGHAM
Bellingham Study Area
Anacortes Study Area
Anacortes
SKAGIT RIVER
ROSARIO STRAIT
VANCOUVER ISLAND
STRAIT OF JUAN DE FUCA
CANADA
U.S.A.
Everett Study Area
STILLAGUAMISH RIVER
PORT ANGELES
Port Angeles Study Area
ADMIRALTY INLET
48°
EVERETT
SNOHOMISH RIVER
OLYMPIC PENINSULA
PACIFIC OCEAN
SOUND
SEATTLE
PUGET SOUND
TACOMA
PUYALLUP RIVER
OLYMPIA
Scale
Nautical Miles
0
10
20

FIGURE 2-1. Puget Sound - General study area.

CLIMATE

The climate of the Puget Sound Basin is typified by cool, dry summers and mild, wet winters. Mean annual temperatures average 51°F and extreme annual temperatures average 3° and 96°F. Predominating air circulation brings moisture-laden air from the Pacific Ocean into the basin. Resulting annual average precipitation ranges from 23 inches in the western sector of the Sound, in the rain shadow formed by the Olympic Mountains, to 41 inches in the eastern sector, where the Cascade Mountains form a rain barrier. Light rains account for most of the precipitation at the lower elevations, whereas heavy winter snows are the predominant form at the higher elevations in the Cascade and Olympic Mountains.

The surface winds over Puget Sound are quite complex and are largely determined by local topography. Average monthly velocities are in the neighborhood of 10 knots. In the Strait of Juan de Fuca, the predominant winds are from the east in the winter and from the west in the summer, with average velocities of about 15 knots. The prevailing winds in each of the four study areas are:

Bellingham --from the west and southwest in the spring, summer, and fall; from the southwest in the winter.

Anacortes--from the southwest and west in the summer; from the southeast in the winter.

Everett--from the northwest in the spring, summer, and fall; from the east and southeast in the winter.

Port Angeles--from the northwest and west during the summer; from the south and southwest in the winter.

TIDES

The ocean tides along the Pacific Coast of North America are of the mixed semi-diurnal type, characterized by two unequal high tides and two unequal low tides occurring during a single day. Generally, tides of similar character occur in Puget Sound. Local geomorphology modifies the basic tide wave, however, such that tidal conditions and tidal ranges vary from point to point throughout the Sound. Mean tidal ranges for the four study areas are:

Area	Mean Tidal Range (feet)
Bellingham	5.2
Anacortes	4.8
Everett	7.4
Port Angeles	4.2

WATER CIRCULATION

Water circulation in Puget Sound is affected by freshwater discharges, winds, and tides. The pattern of currents for the entire Sound is quite complex and too vast a subject for this report. Generally, a net seaward flow of surface waters and a net inward flow of deep waters prevail. The surface flow carries the fresh waters discharged into the Sound outward to sea, while the deep-water flow transports seawater into the Sound. These flows enter and exit through the Straits of Georgia and Juan de Fuca. Local geomorphology and hydrology modify, in varying degree, this generalized situation, and for this reason, the features of water circulation specific to each of the four study areas are discussed in the appropriate sections to follow.

TRIBUTARY STREAMS

Puget Sound receives freshwater runoff from numerous tributary streams. The mean daily discharge for the entire basin, excepting Vancouver Island, is 40,000 to 50,000 second-feet. Extreme basin discharges have been 375,000 and 15,000 second-feet. The Snohomish and Skagit Rivers each carry approximately one-third of the total basin discharge, and the Stillaguamish and Puyallup Rivers each carry about 8% of this total flow. The balance of the freshwater discharge is fairly well distributed throughout the remaining areas of the Sound.

This freshwater inflow establishes throughout the Sound a surface layer of less-saline water overlying more-dense seawater. Near the mouths of the major streams, this surface layer is quite stable and pronounced. Vertical mixing does occur, but does not completely destroy this surface layer. Thus, in areas far removed from river discharges, distinct gradients of increasing salinity (and increasing density) with increasing depth still exist.

MARINE RESOURCES

The naturally rich and productive waters of Puget Sound support and provide a habitat for a variety of fish and shellfish, and these in turn support significant commercial and sport fishing activities. The 1950-1963 average annual commercial harvest of all fish 1/ and shellfish in the Sound amounted to over 89 million pounds (Ward, Robison, and Palmen; 1964) and the average annual wholesale value of the Puget Sound commercial harvest of fish 1/ and shellfish for 1961 to 1963 amounted

---

1/ Excludes Puget Sound landings of halibut, albacore, and silver smelt which are primarily caught outside of the Sound.

to over $10,600,000 (Robison _et al_., 1962; Ward _et al_., 1963 and 1964). An estimated 300,000 sportsmen (Crutchfield, 1963) fish Puget Sound waters and its tributaries for chinook and silver salmon, steelhead trout, and other saltwater fishes. Crabs and clams also are taken by recreationalists. It is estimated that Puget Sound saltwater fishermen spend $50 to $60 million per year for bait, tackle, and boat and other fishing expenses (Crutchfield, _loc_. _cit_.).

The important shellfish inhabiting the Sound are oysters, crabs, hard-shelled clams, octopus, squid, shrimp, and scallops. Pacific and Olympia oysters are commercially cultivated in many areas of the Sound, including Samish Bay in the Bellingham study area and Padilla and Fidalgo Bays in the Anacortes area. Annual harvests range from 3 to 4 million pounds. The other shellfish, particularly crabs and clams, are harvested by both commercial and sport fishermen.

The anadromous fishery of the Sound includes the chinook, silver, sockeye, pink, and chum species of salmon and the steelhead, sea-run cutthroat, and dolly varden species of trout. All of these fish spend their adult life in the saltwaters of Puget Sound and the Pacific Ocean before migrating to tributary streams to spawn. The juveniles of these fish spend varying amounts of time in the nursery streams and the shore waters of the Sound before moving to sea to spend their adulthood. Salmon are a valuable commercial as well as an important game fish. In 1963, commercial fishermen took nearly 7 million salmon, while the sportsmen caught about 785,000. The trout are a regulated game fish, and in the 1962-63 season, sportsmen took over 100,000 steelhead trout in 51 of the tributary streams of the basin.

The saltwater fishery of the Sound includes (by local and common name) rockfish, sole, flounder, lingcod, blackcod, truecod, sharks, rays, skates, ratfish, perch, anchovy, candlefish, hake, herring, pilchard, smelt, turbot, and greenling. All of these fish are commercially harvested, either for their value as food fish or for their incorporation into such products as fertilizer, vitamins, mink food, fish food, and pet foods. The average annual commercial harvest of these fish is about 46 million pounds. Many of these are also taken by the sports fishermen.

Puget Sound also provides an appropriate environment for all those animals and organisms of the food chain for those fish already listed. Such life includes the smaller fishes, zooplankton, phytoplankton, and numerous types of invertebrates. In total, Puget Sound supports a large and diverse community of aquatic life.

3. WATER USES

Principal water uses in Puget Sound are commercial and sports fishing, water recreation, and water transportation. Also, significant usage is realized in the enjoyment of the Sound's scenic beauty. These several uses not only have a distinct impact on the economy of the basin, but they also have a definite social value. As such, the waters of Puget Sound constitute one of the most valuable resources of the State of Washington and the Pacific Northwest. Water uses in each of the four study areas are well developed and include all those itemized above. Waste disposal is another water use but is of particular concern because of its possible impairment to marine life and interference with the other water uses.

COMMERCIAL AND SPORTS FISHING

Commercial and sports fishing are carried out in all parts of Puget Sound. The types of fish and shellfish harvested and the statistics on the annual catches for the entire Sound are given in Section 2.

In the Bellingham and Anacortes areas, several fisheries are important. Commercial fishermen take bottom fish, shrimp, crab, and herring in Bellingham and Samish Bays and crab in Padilla Bay. Lummi Indian fishermen net large catches of salmon in Bellingham Bay near the mouth of the Nooksack River. In the adjoining waters of Rosario Strait and Bellingham Channel, bottom fish, herring, and salmon are caught commercially. The cities of Bellingham and Anacortes are home

Preceding page blank

ports for large, modern fleets which fish the local waters, other parts of the Sound, and Alaskan and Pacific Ocean waters. Excellent harbor facilities and several fish packing and canning plants are located in these two cities. Commercial oyster farming is an important industry in Samish, Padilla, and Fidalgo Bays. These shallow waters are particularly well suited for the culturing of Pacific oysters. Sportsmen fish the Bellingham-Anacortes area for salmon, certain bottom fish, and crabs. Sportsmen also angle for steelhead and sea-run cutthroat trout in the Nooksack and Samish Rivers and in the other tributary streams of the area.

Commercial fishermen take bottom fish, herring and crabs throughout the Everett area, particularly in Saratoga Passage. Salmon are taken by Indian fishermen on the Snohomish River and delta and in Port Susan. Everett is a home port for a large commercial fleet, which fishes both inside and outside the Sound. The Everett area also supports a sports fishery. This includes principally salmon, clams, and crabs in the estuarine waters and steelhead and other trout species in the tributary streams.

In the Strait of Juan de Fuca in the Port Angeles area, commercial fishermen catch salmon and some bottom fishes. As in the other areas, Port Angeles has a large commercial fishing fleet and provides harbor and supporting facilities for this industry. The Strait is also a popular area for sport fishing. Salmon are caught in the Strait, and steelhead and other species of trout are caught in the several small streams of the area, particularly the Elwha River.

RECREATION

Besides sport fishing, clam digging, and the harvest of other shellfish, recreational water uses in Puget Sound include pleasure boating, skin diving, and various beach activities such as swimming, wading, beach combing, and picnicking. These recreational opportunities are important and highly treasured benefits of employment and residency in the region, and they play a major role in attracting visitors and tourists to the area. Pleasure boating and its associated activities are served by excellent marinas, yacht clubs, and other supporting facilities throughout the Sound, including the four study areas. Skin diving finds popularity by virtue of the varied marine life of the Sound and the clear waters found in many parts thereof--the Port Angeles area being one of the most popular of these. Fine beaches and parks, and miles of scenic shoreline are found throughout the Sound and in all four of the study areas. These provide sites for a variety of beach and water-oriented recreational activities.

SHIPPING

The navigability of Puget Sound brings in water-borne commerce of all types. This includes deep-draft, foreign and coastal shipping; coastal and intra-sound barge traffic; ferry traffic; and log rafting. The principal commodities carried are crude oil, grains, logs, wood chips, and forest products including wood pulp and paper. Bellingham, Anacortes, Everett, and Port Angeles are all major ports, and each provides navigable channels and docking facilities capable of handling all types of vessels. Together, these four cities handle about one-third of the total Puget Sound shipping.

OTHER

Water usage resulting from the scenic beauty of Puget Sound is not to be overlooked. This includes its use as a beautiful setting and view for homes and summer cottages, and as a pleasing background for picnics, beach activities, and automobile trips. Throughout the entire Sound, including all four of the study areas, the scenic attractiveness of the Puget Sound waters is enjoyed by both tourists and residents alike.

4. WASTE DISPOSAL

The disposal of wastes into estuarine waters is a common practice throughout the Puget Sound Basin. The regulation of this water use, so as to prevent water pollution and safeguard the quality of natural waters, is the responsibility of the Washington State Pollution Control Commission. The State's pollution control legislation states, "It is declared to be the public policy of the State of Washington to maintain the highest possible standards to insure the purity of waters of the State . . . . . and to that end require the use of all known available and reasonable methods by industries and others to prevent and control the pollution of waters of the State of Washington." The Commission regulates municipal waste disposal on an individual basis, through appropriate communications with the particular community. Regulation of industrial waste disposal is accomplished under a system of waste discharge permits, which are classed as either temporary or permanent. Temporary permits are granted under terms requiring further investigation of the pollutional impact of the wastes from an industry or pending the installation of adequate waste treatment facilities within a reasonable period of time. Permanent permits are valid for five years and are issued to industries which have satisfied the Commission's pollution abatement requirements. All industries must hold permits. Where these procedures fail, the Commission has enforcement powers which may be exercised through hearings and legal action.

A recent inventory by the Commission lists 178 separate waste sources which discharge into Puget Sound. This list contains 23 fish and shellfish plants and 4 oil refineries, all of which have permanent permits. For the food processing industry, 29 sources are listed; 27 have permanent permits and two have temporary permits for need of additional treatment facilities. The pulp and paper industry has 13 sources. All of these hold permanent permits, but the 7 mills considered in this report are discharging wastes of undetermined pollutional impact. Of the 30 miscellaneous industrial waste sources, including chemical, metal, quarrying, and other industries, 29 hold permanent permits and 1 holds a temporary permit because of unsatisfactory waste treatment practices. Sixty-five municipal waste sources are listed, and of these, 45 provide satisfactory treatment while 20 are classed as requiring new or additional treatment facilities. In summary, most sources have controlled, by means of adequate treatment or disposal methods, their waste discharges into Puget Sound so as to minimize pollution and interferences with other water uses. Exceptions to this are 7 pulp and paper mills, 3 other industries, and 20 communities. These sources are being investigated or have been ordered to provide adequate waste control facilities.

Part 2

BELLINGHAM STUDIES

5. INTRODUCTION

The principal waste source in the Bellingham area is the sulfite pulp and board mill operated by the Georgia-Pacific Corporation (Figure 5-1). Process wastes are discharged into the surface waters of Whatcom Waterway and are subsequently dispersed throughout Bellingham Harbor and the Bellingham-Samish Bay system.

Other major waste sources in the Bellingham area are the Georgia-Pacific Corporation paper mill, the City of Bellingham sewage treatment plant, the Fairhaven outfall sewers, the Bumble Bee Seafood fish cannery, and the Stokely-Van Camp pea cannery. The locations of these sources are shown in Figure 5-1.

STUDY AREA

The Bellingham study area (Figure 5-2) includes Bellingham and Samish Bays and Hale Passage. Principal tributary streams are the Nooksack and Samish Rivers. The only sizable community in the area is the City of Bellingham which includes suburban South Bellingham. To the south of the Bellingham-Samish Bay system lies the Anacortes study area--Padilla and Fidalgo Bays, and Guemes Channel--also shown in Figure 5-2.

By definition, Bellingham Bay includes all waters of the study area except Samish Bay (note the arbitrary boundary, Figure 5-2). On its west side, the Bay opens to Rosario Strait, and through this opening pass most of the tidal waters exchanged between the study area

Preceding page blank

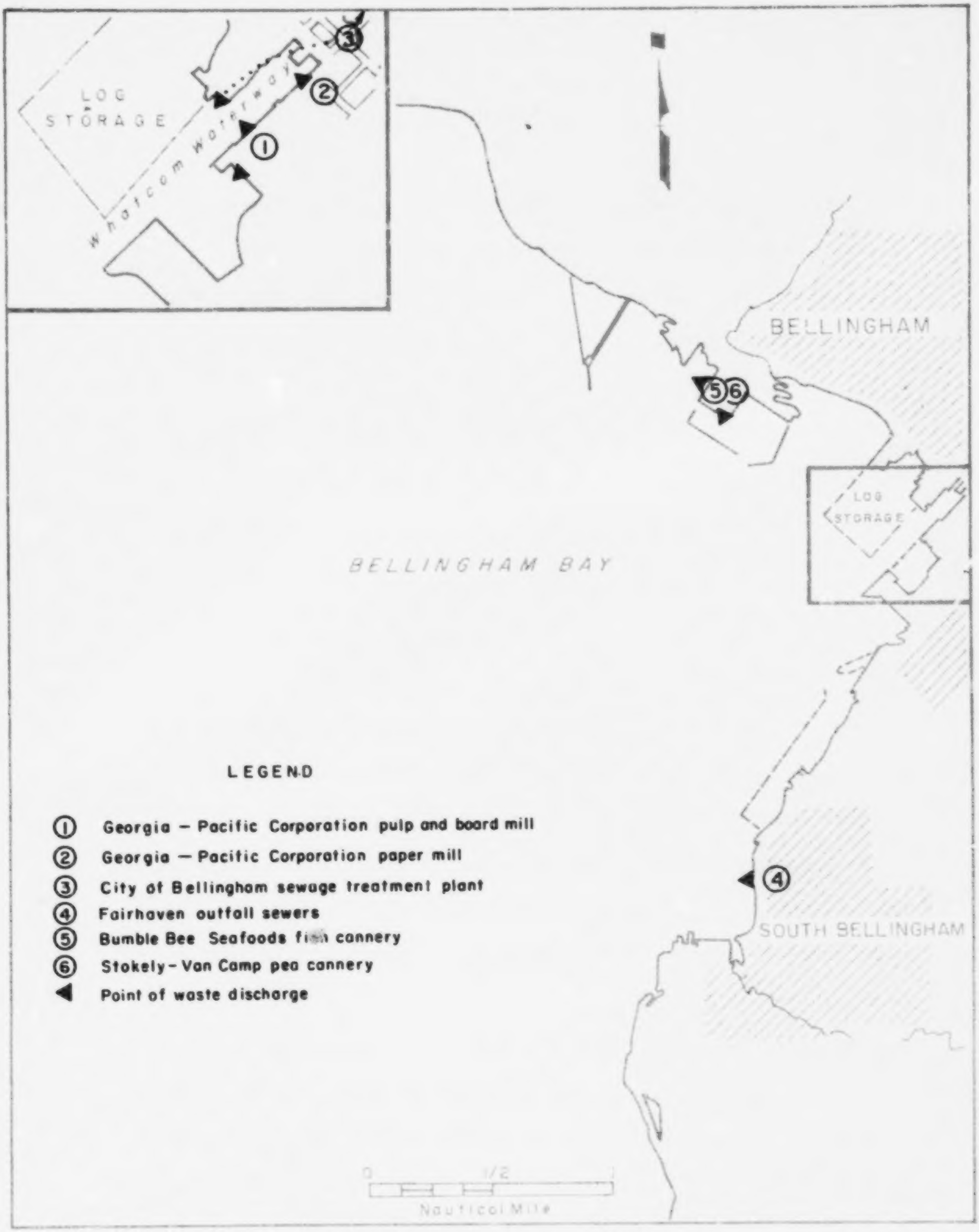

LOG STORAGE
Whatcom Waterway
①
②
③
BELLINGHAM
⑤⑥
LOG STORAGE
BELLINGHAM BAY
④
SOUTH BELLINGHAM
LEGEND
① Georgia – Pacific Corporation pulp and board mill
② Georgia – Pacific Corporation paper mill
③ City of Bellingham sewage treatment plant
④ Fairhaven outfall sewers
⑤ Bumble Bee Seafoods fish cannery
⑥ Stokely-Van Camp pea cannery
◀ Point of waste discharge
0
1/2
1
Nautical Mile

FIGURE 5-1. Waste sources in Bellingham area.

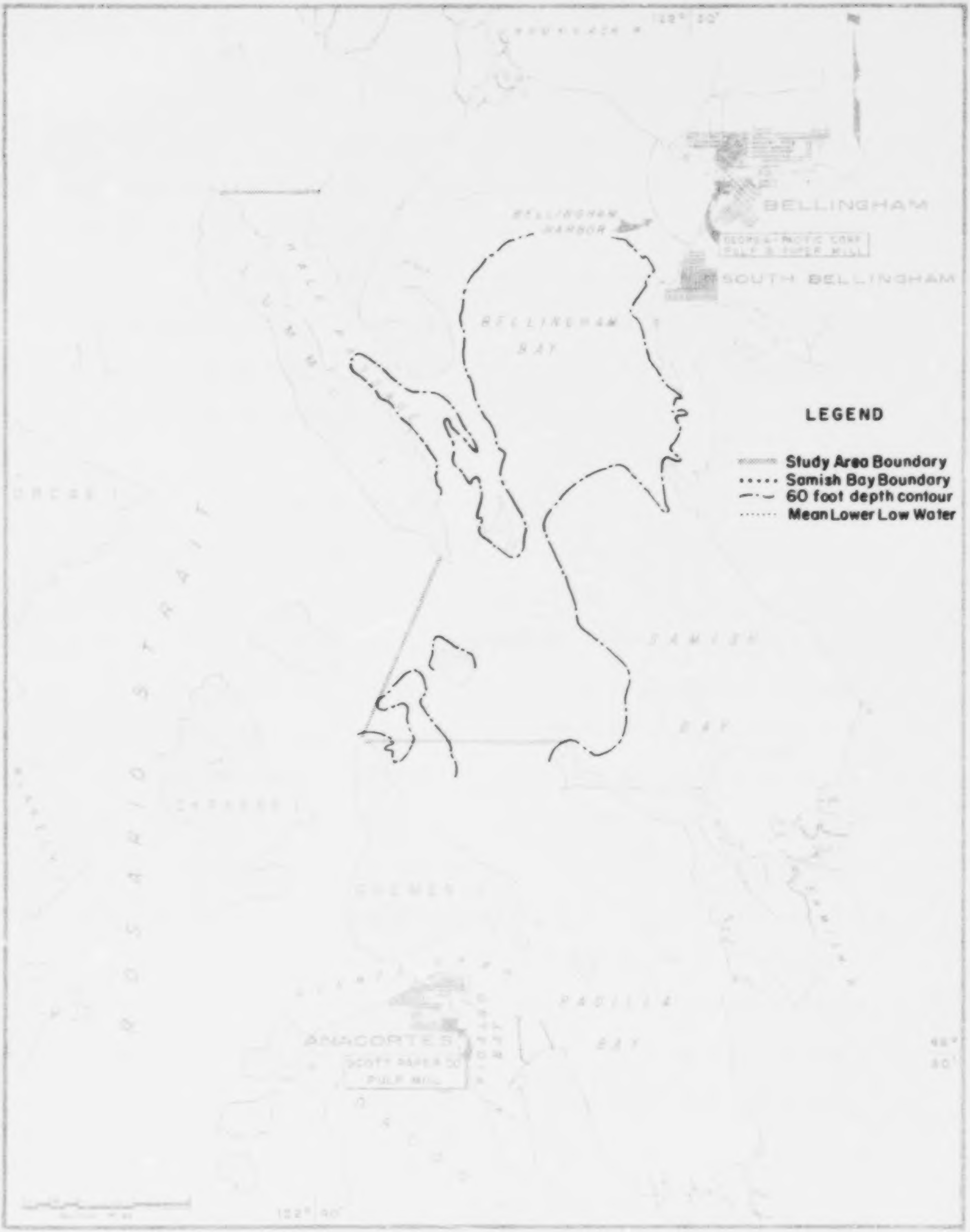

BELLINGHAM
GEORGIA-PACIFIC CORP. PULP & PAPER MILL
SOUTH BELLINGHAM
BELLINGHAM HARBOR
BELLINGHAM BAY
SAMISH BAY
PADILLA BAY
ROSARIO STRAIT
ANACORTES
SCOTT PAPER CO. PULP MILL
LEGEND
Study Area Boundary
Samish Bay Boundary
60 foot depth contour
Mean Lower Low Water
122° 30'
122° 40'
48° 30'

FIGURE 5-2. Bellingham study area.

Reproduced from best available copy.

and other parts of Puget Sound. Some tidal exchange also passes through Hale Passage and through the opening to Padilla Bay. Bellingham Bay is relatively shallow; depths throughout much of the Bay are less than 60 feet (Figure 5-2). Depths greater than 110 feet occur in a small area south and east of Lummi Island.

Bellingham Harbor is that part of the Bellingham Bay fronting the City of Bellingham and, by definition, enclosed in an arc of 1-1/3 miles radius (Figure 5-2). Whatcom Waterway (Figure 5-1) is a part of the Harbor.

Samish Bay also is shallow. Depths throughout most of the Bay are less than 60 feet, and tide flats which become exposed at low tides cover a large area. Pacific oysters are commercially grown in the Bay.

The Nooksack River, the largest tributary to the area, carries an average daily flow of over 3,700 second-feet and extreme daily flows of 46,200 and 595 second-feet. It is an important rearing stream for anadromous fish, and its discharges have considerable influence on water circulation in Bellingham Bay. Samish River, the second largest tributary, carries an average daily flow of 250 second-feet and extreme daily discharges of 5,830 and 11 second-feet. Other tributaries to the area include Squalicum and Whatcom Creeks which discharge into Bellingham Harbor, Padden Creek which discharges into Bellingham Bay near South Bellingham, and Chuckanut Creek which discharges into Chuckanut Bay. These carry very small flows.

6. WASTES

STUDIES

Three in-plant surveys were conducted at the Georgia-Pacific pulp and board mill (hereafter referred to as the Georgia-Pacific mill) during February 11-14, 1963; December 9-12, 1963; and July 13-16, 1964. Each survey covered a 72-hour period, usually starting at 8 a.m. on Monday and terminating at 8 a.m. on Thursday. Three 24-hour composite samples and additional grab samples were collected from each of several in-plant waste streams.

Other major waste sources in the Bellingham area were surveyed on the following dates:

Georgia-Pacific paper mill	March 1-3, 1965
City of Bellingham sewage treatment plant	September 29, 1964
Fairhaven outfall sewers	August 4, 1965
Stokely-Van Camp pea cannery	August 5, 1965
Bumble Bee Seafoods fish cannery	August 5, 1965

The details of these surveys are given later.

METHODS

The survey program at the Georgia-Pacific mill was a cooperative effort of the Project, the Washington State Pollution Control Commission, and the mill's technical staff. Pre-survey meetings were held to define scheduling, sampling points, survey methods, and analytical procedures. Composite samples collected during the survey were split between the Project and the mill for independent and duplicate analyses. A manual of analytical methods prepared by the Project was used by both parties. Post-survey meetings were held after samples had been analyzed and results tabulated. Data were compared and exchanged, discrepancies were discussed and resolved, and information on waste flows and mill production were provided by the mill.

The twenty-four-hour composite samples were collected by automatic equipment, where installed. Otherwise, these were made up of grab samples collected at 30-minute intervals. Sample analyses, by both the Project and the mill, included:

BOD: both 5-day and 20-day BOD by methods in A.P.H.A. (1962).

COD: by the method in A.P.H.A. (1962) with the addition of mercuric sulfate to correct for chloride interference.

SWL: by the modified Pearl-Benson method (Barnes, *et al*.; 1963).

Total Sulfur: by a perchloric-acid oxidation, barium-sulfate precipitation method developed by W. O. Winkler of the Project staff.

Total Solids: both fixed and volatile by methods in A.P.H.A. (1962) but modified by adjustment of sample pH to 5.2.

Suspended Solids: both fixed and volatile by the methods in A.P.H.A. (1962) but modified by the use of glass-fiber filter paper under the asbestos mat.

Supernatant Suspended Solids: by the method in A.P.H.A. (1962) but modified as above.

In addition to composite samples, grab samples were periodically collected from each waste stream. These were analyzed for pH (pH meter) and settleable solids (Imhoff cone).

Surveys of the other wastes sources were conducted by the Washington State Pollution Control Commission. Methods similar to those described above were employed.

RESULTS

Georgia-Pacific Pulp and Board Mill. This plant operates a calcium-base sulfite mill producing about 527 tons of pulp per day, a board mill producing about 40 tons of paper board per day, and a waste liquor recovery plant producing the marketable by-products, alcohol and dried liquor solids. A semi-groundwood mill recently was put into operation, but after completion of in-plant surveys; thus no waste information was obtained.

Figure 6-1 is a schematic diagram of the mill layout and sewer system. Survey sampling points are shown, also. Process wastes are discharged into Whatcom Waterway and the log pond (both receiving waters are common to Bellingham Harbor). Sanitary wastes are collected and treated by the City of Bellingham.

Averaged results from the three surveys are tabulated in Table 6-1. Waste loads from the pulp mill and board mill are listed separately, and they reveal that the pulp mill is the larger source of wastes.

The Georgia-Pacific mill is unique among the Puget Sound pulp and paper mills in that it utilizes sulfite waste liquor for the production of alcohol and dried liquor solids. Approximately one million gallons

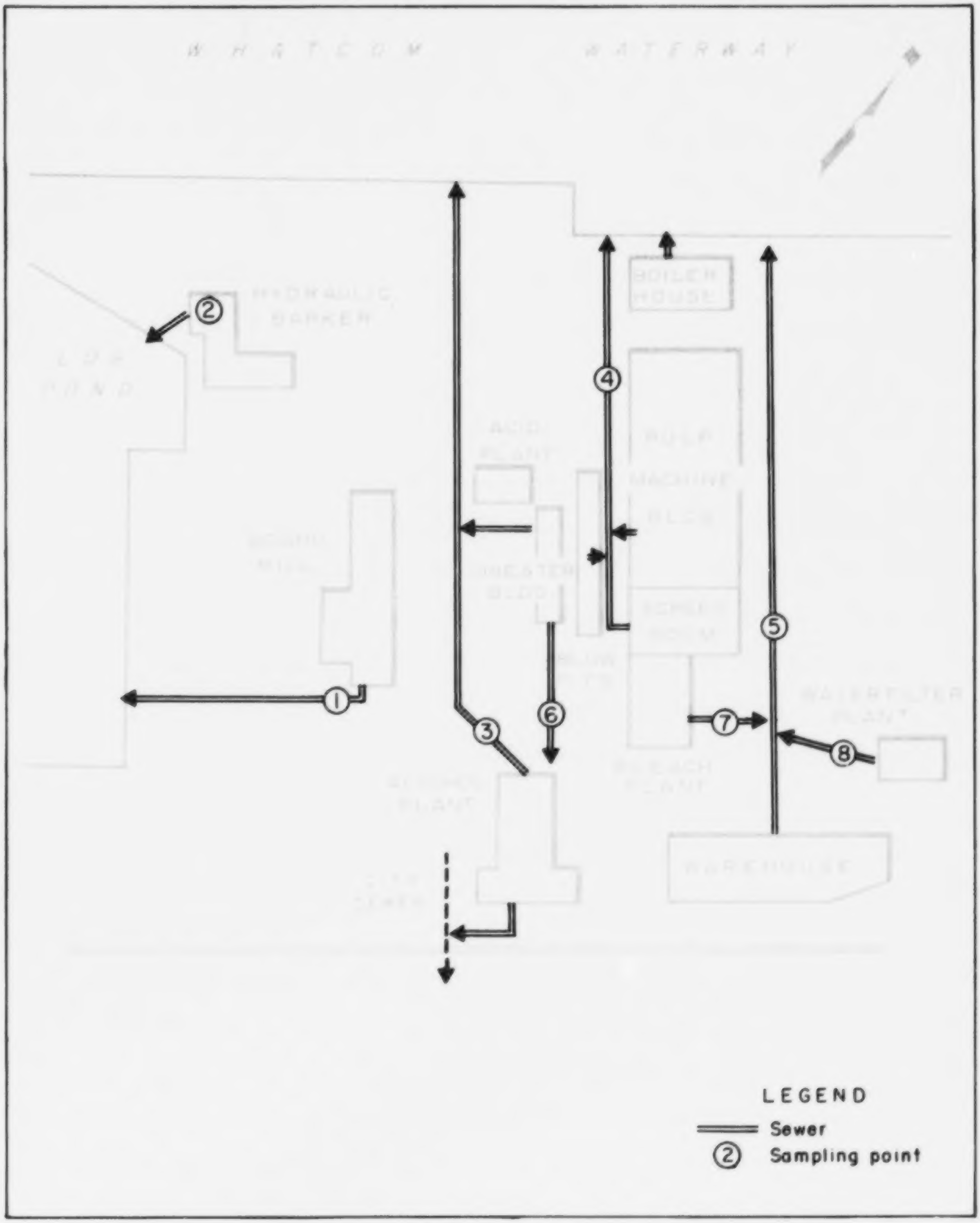

WHATCOM WATERWAY
LOG POND
HYDRAULIC BARKER
BOILER HOUSE
ACID PLANT
PULP MACHINE BLDG
BOARD MILL
DIGESTER BLDG
SCREEN ROOM
BLOW PITS
WATERFILTER PLANT
BLEACH PLANT
ALCOHOL PLANT
CITY SEWER
WAREHOUSE
①
②
③
④
⑤
⑥
⑦
⑧
LEGEND
Sewer
② Sampling point

FIGURE 6-1. Schematic diagram of mill layout, sewer system, and sampling points; Georgia-Pacific Corporation pulp & board mill, Bellingham, Washington.

TABLE 6-1. Average daily waste loads discharged by the Georgia-Pacific pulp and board mill in Bellingham, Washington.

Analyses	Pulp Mill #/Ton of Production	Pulp Mill Tons/Day	Board Mill #/Ton of Production	Board Mill Tons/Day
BOD_5	519	139	32.1	0.5
COD	2,547	677	105.7	1.7
SWL*	22,960	6,032	316	5.0
Total Sulfur	149	39.5	--	--
Total Solids	2,154	571	126	2.1
Volatile	1,663	427	75	1.3
Suspended Solids	43.4	12.6	64.9	1.1
Volatile	38.6	11.0	40.2	0.6
Supernatant Susp. Solids	19.2	5.2	39.0	0.6
Ave. Tons Production/Day (air dried)	527		40	
Ave. % Volatile Susp. Solids Loss	1.9		2.0	
Ave. Waste Volume, mgd	32.6		1.2	

*Weight of a 10% solids solution, per ton or per day as indicated.

per day of digester strength liquor are directed to a fermentation plant where a yeast culture produces alcohol by utilization of the fermentable sugars in the liquor. About 11,000 gallons per day of alcohol are produced. A reported 35-50% of the alcohol plant effluent is evaporated and dried to produce dried liquor solids. The alcohol fermentation process, in consuming wood sugars, reduces the oxygen demand of the mill's wastes, and evaporation and drying of alcohol plant effluent, in removing additional sugars and liquor solids, reduces the total solids and PBI of the mill's waste load. Thus, the by-product recovery practices of the Georgia-Pacific mill effect a partial removal of pollutants that would otherwise be discharged into Bellingham Harbor.

Georgia-Pacific Paper Mill. This mill is located adjacent to the Georgia-Pacific pulp and board mill but is a separate manufacturing facility. On six paper machines, it produces about 164 tons per day of tissue paper products. Process wastes are discharged into Whatcom Waterway via a single sewer (see Figure 5-1).

Three, 24-hour composite samples of the total waste discharge were collected at this mill. Averaged results are tabulated in Table 6-2.

Bellingham Sewage Treatment Plant. This primary treatment plant serves a sewered population of 40,000. Mechanically-cleaned sedimentation facilities, separate sludge digestion and disposal, and effluent chlorination are provided. Effluent is discharged into Whatcom Waterway (see Figure 5-1).

A 12-hour composite sample of effluent was collected between 6:00 am and 4:00 pm. Average recorded flow during the survey was 5 mgd. Results, as interpolated for a 24-hour day, are tabulated in Table 6-2.

Fairhaven Outfall Sewers. Untreated domestic wastes from a population of about 6,300 in the South Bellingham area are carried by

TABLE 6-2. Average daily waste loads discharged by other major waste sources in the Bellingham area.

	Tons/Day				
Analyses	Georgia-Pacific Paper Mill	Bellingham Sewage Treatment Plant	Fairhaven Outfall Sewer	Stokely-Van Camp [1]	Bumble Bee Seafoods [1]
BOD_5	1.7	3.6	0.2	2.8	4.3
COD	5.5	- -	- -	- -	- -
Apparent SWL [2]	1.7	- -	< 0.1	0.5	0.1
Total Solids	6.4	- -	0.9	7.7	5.3
Volatile	4.8	- -	0.4	3.8	4.7
Suspended Solids	4.1	1.2	0.3	0.6	3.8
Volatile	3.8	1.0	0.2	0.4	3.7
Supernatant Susp. Solids	1.0	- -	- -	- -	- -
Waste Volume, mgd	5.3	5.0	0.8	0.9	0.3

[1] Very intermittent canning operations -- wastes loads given are estimated maximum daily loads.

[2] From non-pulping constituents which give an apparent-SWL indication in the Pearl Benson test -- equivalent to tons of a 10% solid SWL solution per day.

these two sewers. They discharge into Bellingham Bay within a block of each other (see Figure 5-1).

Single grab samples were taken from each sewer at 10:00 am and 3:00 pm on August 4, 1965, and these were combined. Waste flows were estimated from observed sewer water depth and velocity. Combined results, as interpolated for a 24-hour period, are listed in Table 6-2.

Stokely-Van Camp. This plant processes peas intermittently during the harvest season. Wastes are screened and discharged into the Bellingham Boat Harbor (see Figure 5-1).

A 10-hour composite sample of this plant's total waste stream was collected on a day when it operated 16 hours and processed 169,900 pounds of peas. Results, as interpolated for a 16-hour day, are tabulated in Table 6-2.

Bumble Bee Seafoods. This plant processes salmon in season. Operation is intermittent. Wastes are screened and pumped to a discharge point outside of the Bellingham Boat Harbor (see Figure 5-1).

An 8-hour composite sample of the plant's total waste stream was collected on a day when it operated at one-third capacity and processed 240,000 pounds of salmon in a 21-hour period. Results, as interpolated for full capacity and 16-hours daily operation, are given in Table 6-2.

DISCUSSION

In Figure 6-2, the average daily waste loads from the Georgia-Pacific pulp and board mill are compared with the combined daily waste loads from other sources in the area; viz., the Georgia-Pacific paper mill, Bellingham sewage treatment plant, Fairhaven outfall sewers,

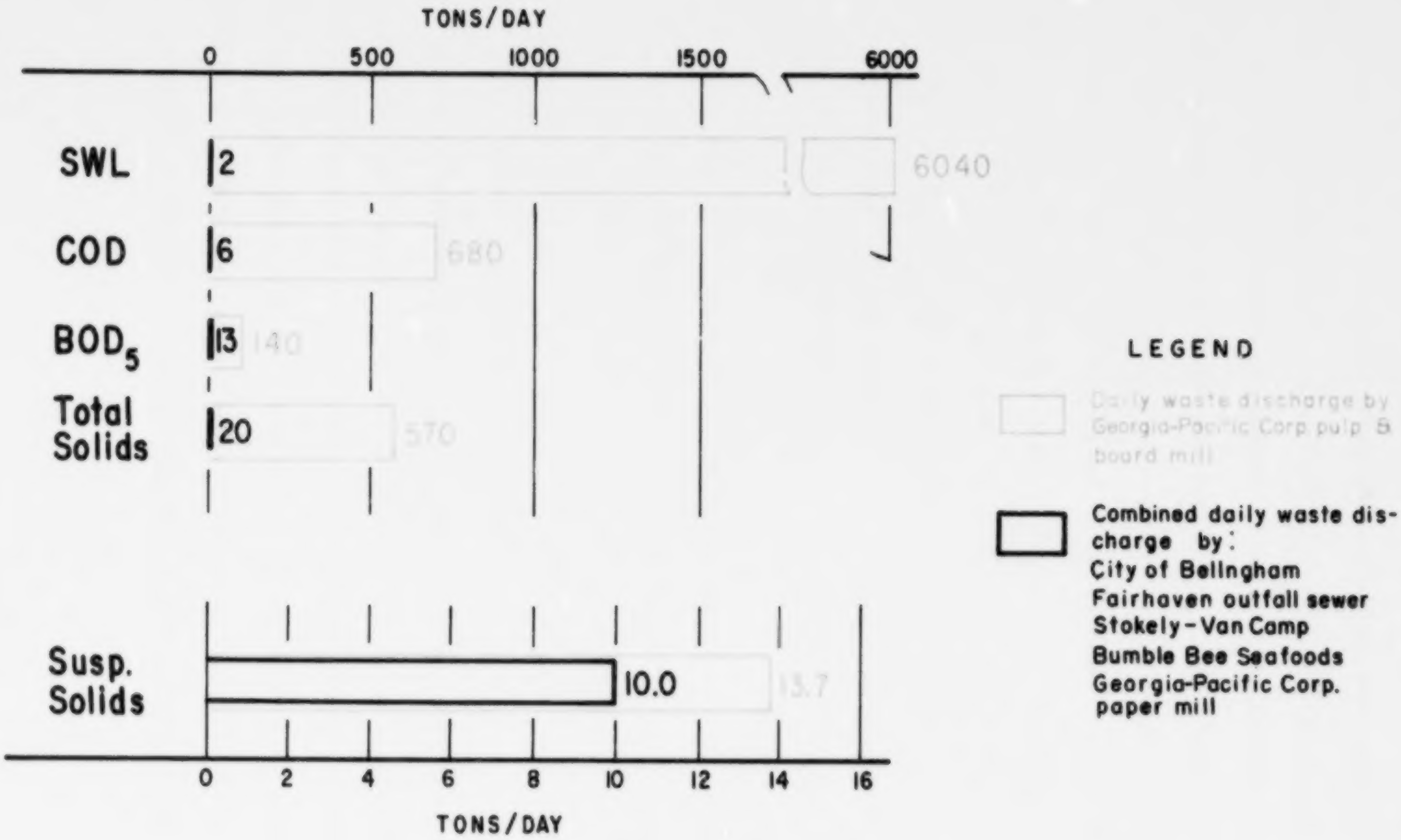


FIGURE 6-2. Comparison of total daily waste loads discharged into Bellingham Bay.

Stokely-Van Camp, and Bumble Bee Seafoods. Note, that for the waste load categories of SWL, COD, BOD_5, and total solids, the Georgia-Pacific mill is clearly the major source. Obviously, any abatement of pollution attributable to these waste properties (discussed in the following sections) will necessitate further treatment or recovery of this mill's waste, over and above the alcohol and dried liquor solids by-product recovery now practiced. This does not imply, however, that the other waste sources have adequate treatment. Without a doubt, the discharge of raw sewage from the Fairhaven outfall sewers needs immediate correction. Also, it is recognized that the mere screening of wastes from the Stokely-Van Camp and Bumble Bee Seafoods canneries is minimal treatment.

Substantial amounts of suspended solids are discharged by both the Georgia-Pacific mill and the other waste sources (Figure 6-2). Settling tests (Imhoff cone) indicate that the 13.7 tons per day suspended solids loss from the Georgia-Pacific mill could be reduced to about 6 tons per day by adequate sedimentation facilities. Also, settling tests indicated that the 4.1 tons per day solids loss from the Georgia-Pacific paper mill could be reduced, through sedimentation, to about 2 tons per day. Finally, primary treatment of the wastes discharged by the Fairhaven outfall sewer, and the Stokely-Van Camp and Bumble Bee Seafoods canneries could significantly reduce the total 4.7 tons per day suspended solids load presently emitted by these sources.

7. WASTE DISTRIBUTION AND WATER QUALITY

STUDIES

For the purpose of (1) describing the distribution of wastes discharged by the Georgia-Pacific mill, and (2) determining the effects of these wastes on water quality and bottom sediments, the Project conducted oceanographic and related studies in the Bellingham area. These investigations included field studies by the Project, and literature search and evaluation of the considerable body of information collected in independent study by outside agencies and institutions.

Circulation Studies. The Project completed two float studies--one on October 18, 1962 when four floats were released in Whatcom Waterway and one on October 19, 1962 when eight floats were released in the northeastern corner of Bellingham Bay. Each float was a crossed-vane current drogue suspended three feet below a marker buoy. Each was released from a small boat and a sextant was used to determine the course of its subsequent movement.

In 1964-65, the U. S. Coast and Geodetic Survey (U.S.C.&G.S.) obtained current data at numerous stations throughout northern Puget Sound, including the Bellingham-Anacortes area (see Figure 7-9 for station locations). At each station, anchored meters were used to monitor current speed and direction at each of three depths for a 100-hour period. Summarized station data were provided the Project as graphs of current speed and direction.

The University of Washington Department of Oceanography conducted two 21-day circulation studies in Bellingham Bay during May-July 1963. Anchored, Richardson-type meters were employed for hourly monitoring of current speed and direction at selected depths at each of the stations shown in Figure 7-1A. Unpublished data are available from the University. These studies were sponsored, in part, by the Georgia-Pacific Corporation; the Project provided thirteen of the meters used.

In addition to actual measurement of water movement by floats and meters, net water circulation patterns were inferred from patterns of average SWL and salinity distribution as observed in the waste distribution and water quality studies.

Waste Distribution and Water Quality Studies. The Washington State Department of Fisheries made 27 water sampling cruises between September 1956 and September 1959. Each cruise normally covered a network of 31 sampling stations (Figure 7-1B) in the Bellingham-Anacortes area. Properties sampled at surface and 20 feet were temperature, salinity, DO, SWL, inorganic phosphate, and chlorophyll (surface only). This work was reported by Westley (1957 and 1960) and by Westley and Tarr (1959 and 1960).

The University of Washington Department of Oceanography made 14 water sampling cruises between November 1959 and November 1961. Each cruise covered 26 stations (Figure 7-1C) in the Bellingham-Samish Bay system. Properties sampled at selected depths to the bottom were temperature, salinity, DO, SWL, and inorganic phosphate. Data were presented by Collias and Barnes (1962). This work was done under

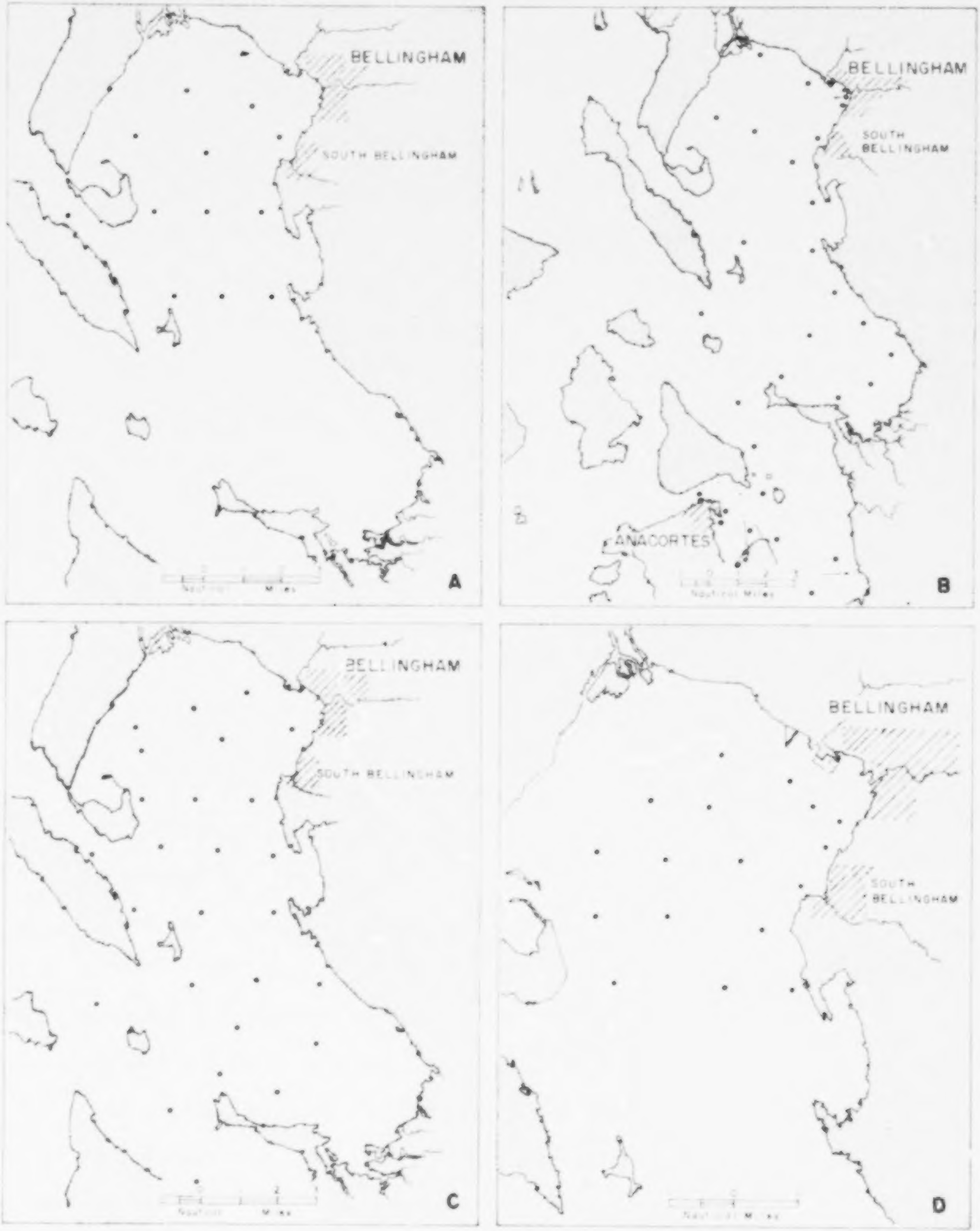

BELLINGHAM
SOUTH BELLINGHAM
Nautical Miles
A
BELLINGHAM
SOUTH BELLINGHAM
ANACORTES
Nautical Miles
B
BELLINGHAM
SOUTH BELLINGHAM
Nautical Miles
C
BELLINGHAM
SOUTH BELLINGHAM
Nautical Miles
D

FIGURE 7-1. Station locations in Bellingham area: (A) current-meter stations of University of Washington Oceanography, May-July 1963; and water sampling stations of (B) Washington Department Fisheries, September 1956-September 1959, (C) University of Washington Oceanography, November 1959-November 1961, and (D) Project, October 1962-December 1964.

contract for the Puget Sound Pulp and Timber Company (now Georgia-Pacific Corporation) and the Office of Naval Research.

The Washington Pollution Control Commission conducted 16 water sampling cruises in various parts of the Bellingham-Anacortes area in 1957-58. Water properties sampled at the surface and bottom, and occasionally mid-depth, were temperature, salinity, DO, and SWL. This work was reported by W.P.C.C. (1958) and Wagner, *et al*. (1957).

The Project conducted 16 water sampling cruises in Bellingham Bay between October 1962 and December 1964. Principal sampling stations occupied on each cruise are shown in Figure 7-1D. Depths sampled were 0, 2, 4, 7, 10, 20, 30, 50, and 70 meters, total water depth permitting. Additional stations and depths were sampled as necessary. Water properties measured were temperature, salinity, DO, pH, and SWL. Water clarity, wind, and weather also were noted.

The Project collected water quality data in Bellingham Harbor during the juvenile salmon bioassay studies of May 12-14 and May 26-28, 1964 (see Section 8). In these, surface samples were taken for determination of temperature, salinity, DO, pH, SWL, and H_2S. The Project also collected water quality data in several of its other biological studies (see Sections 10, 11, 13, 14, and 15).

Bottom Deposit Studies. The University of Washington Department of Oceanography took 82 dredge and core samples of bottom sediments in the Bellingham-Samish Bay system in 1960. Samples were analyzed for color, odor, particle-size distribution, and course fraction constituents including wood chips and fragments. This work was reported by Sternberg (1961).

The Project conducted three studies in Bellingham Bay to describe the composition, amount, and areal coverage of bottom sludge deposits. On May 1, 1963, a gravity core-sampler was used to collect samples two inches in diameter and up to six feet in length from those stations shown in Figure 7-2A. Samples were examined for color, odor, composition, and vertical distribution of particle size. On August 11, 1964, bottom samples were collected with a van Veen dredge at locations shown in Figure 7-2B. These samples were examined in the field for odor, color, and inclusion of wood fiber, wood fragments, and other constituents. In the laboratory, portions of these samples were analyzed for volatile solids content and were examined for the identification and enumeration of included benthos (see Section 9). In the third study, on May 10, 1966, bottom samples were taken with an Ekman dredge from those stations shown in Figure 7-2C. These were examined in the field and analyzed in the laboratory in the same manner as those collected in August 1964.

METHODS

Project studies, for the most part, were conducted from the 45-foot research vessel, HAROLD W. STREETER. This vessel is equipped with a chemistry laboratory and navigational and oceanographic sampling equipment. For some sampling, however, particularly in Bellingham Harbor and adjacent nearshore waters, outboard-motor boats were used.

Water samples were collected with 1.25-liter Nansen bottles or 3-liter Kemmerer samplers. Usual analyses were:

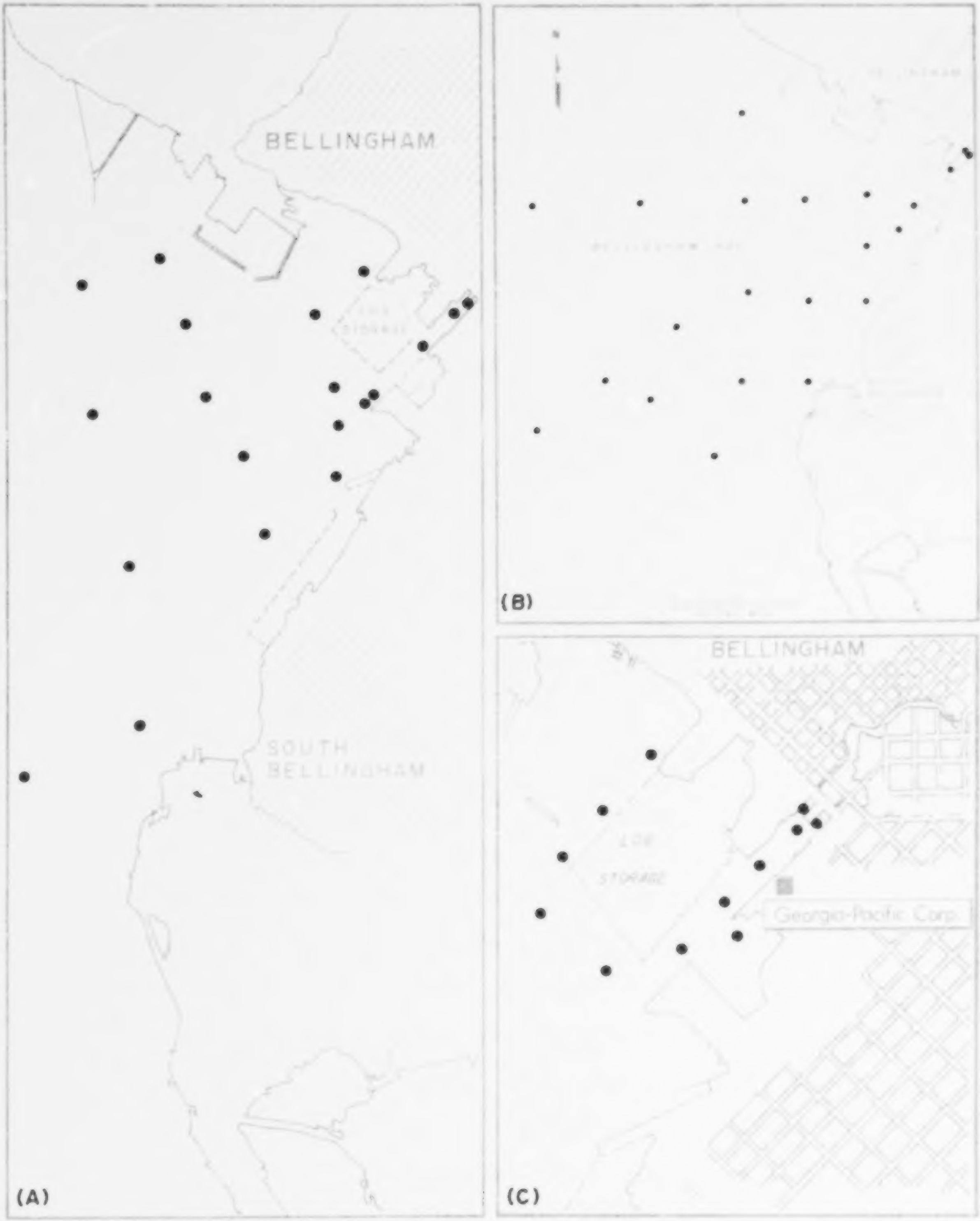

BELLINGHAM
LOG STORAGE
SOUTH BELLINGHAM
(A)
BELLINGHAM
BELLINGHAM BAY
(B)
BELLINGHAM
LOG STORAGE
Georgia-Pacific Corp.
(C)

FIGURE 7-2. Bottom sediment sampling stations in Bellingham Bay: (A) core samples of May 1, 1963; (B) dredge samples of August 11, 1964; and (C) dredge samples of May 10, 1966.

Temperature: with reversing mercury thermometers attached to the Nansen bottles. In some cases, a continuous record of temperature vs. depth was taken with a bathythermograph.

Salinity: with a Hytech,* Model 6210, inductive salinometer.

_DO_: by the Alsterberg modification of the Winkler method (A.P.H.A., 1962).

_pH_: with a Beckman, Model GS, meter.

SWL (10% solids): by the modified Pearl-Benson method (Barnes, _et al_., 1963).

Water Clarity (_in situ_): with a 30 cm diameter Secchi disc. In some cases, _in situ_ measurements of temperature and salinity were taken with an Industrial Instruments, Model RS-5, inductive salinometer. Also, in areas where high SWL concentrations were found to interfere with the Winkler DO test, a Beckman, Model 777, probe was used to analyze for dissolved oxygen, both _in situ_ and in the laboratory.

Bottom samples for volatile solids analyses were frozen in the field, delivered to the laboratory, and analyzed by the method in A.P.H.A. (1962). Results were expressed as percent volatile solids, dry-weight basis.

Methods employed in those studies by other agencies and institutions are described in the references cited. Generally, these methods were similar to those described above.

---

* Mention of products and manufacturers in this report is for identification only and does not imply endorsement by the Federal Water Pollution Control Administration or the Washington State Pollution Control Commission.

RESULTS

Surface Layer. Freshwater discharges, primarily from the Nooksack River but also from other tributaries to the study area, form a surface layer of less saline water, 5 to about 12 feet deep, covering most of Bellingham-Samish Bays. Within this layer, salinity increases rapidly with depth--but below, it increases much more gradually. Consequently, the lower boundary of this layer is delimited by points where the vertical salinity gradient changes. These features are illustrated in Figure 7-3 by the vertical distribution of average salinity (solid line) at each of three stations.

Density stratification associated with the surface layer retards vertical mixing; hence, this layer is maintained as a relatively stable and distinct body of water. Stability does decrease with distance from the freshwater sources, however, because the freshwater forming this layer must flow to sea and as it flows, the slight vertical mixing permitted gradually entrains underlying saltwater and reduces density stratification. Therefore, with increasing distance from the Nooksack River, surface salinities increase (Figure 7-4) and the surface layer deepens (Figure 7-3).

Georgia-Pacific wastes are discharged into near-surface waters. Being less dense than deeper waters, these wastes are entrained in the surface layer and, because of reduced vertical mixing, their subsequent distribution is largely confined to the surface layer waters of the study area; note the vertical distributions of average SWL (dashed lines) in Figure 7-3. Estimates of the average mass-distribution

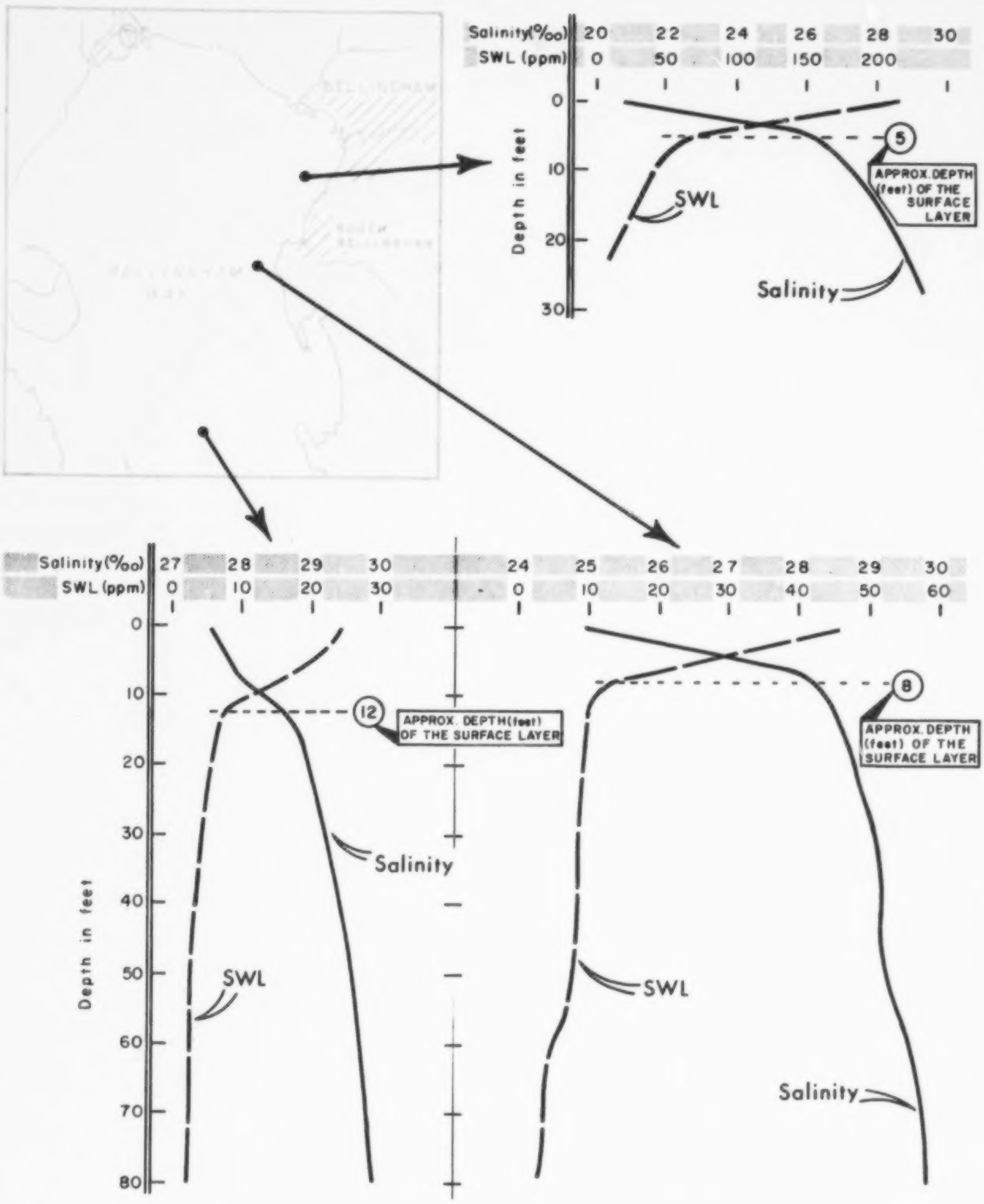


FIGURE 7-3. Vertical distribution of average salinity and average SWL at three stations in Bellingham Bay--data from University of Washington study of November 1959 - November 1961.

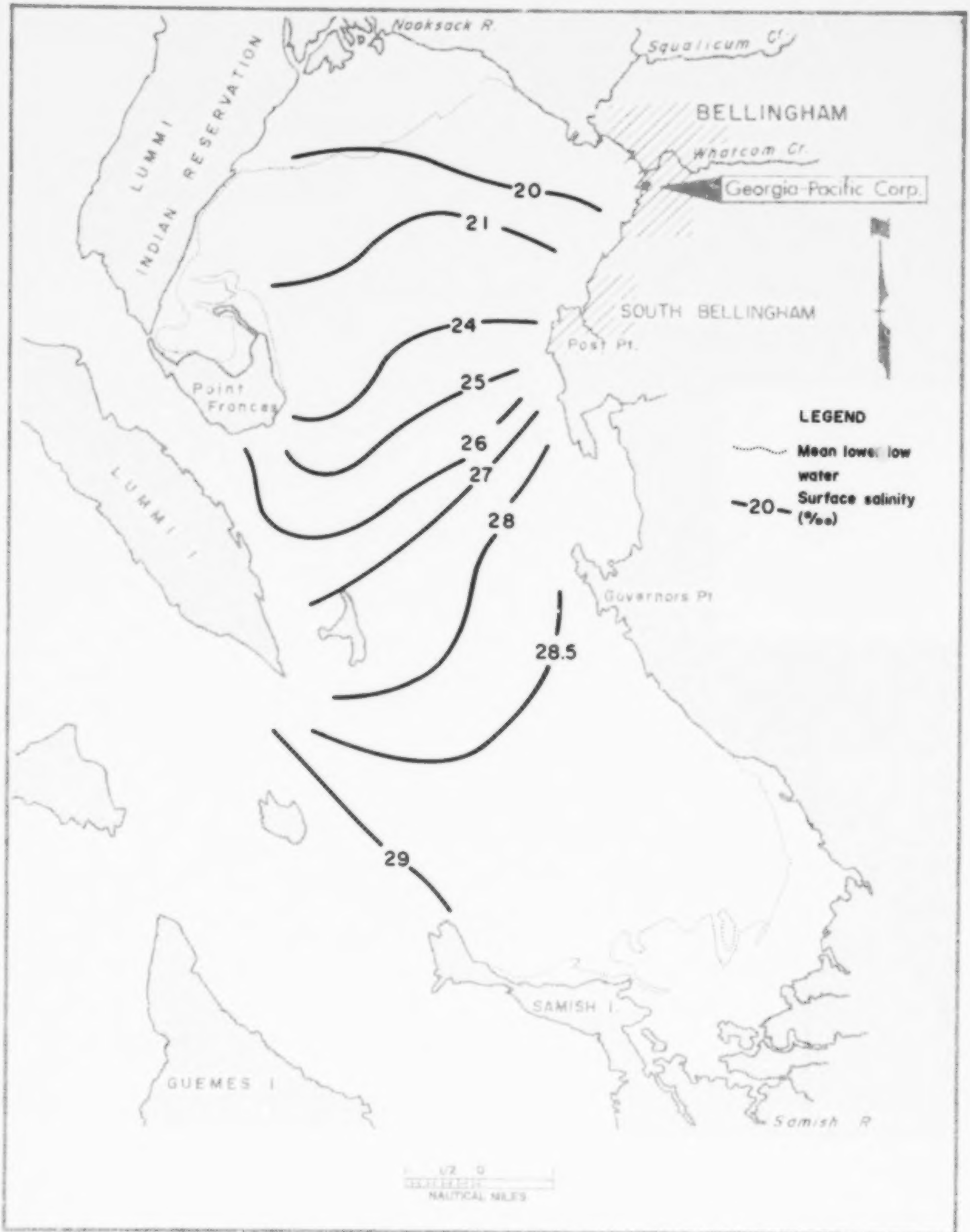

Nooksack R.
Squalicum Cr.
BELLINGHAM
Whatcom Cr.
Georgia-Pacific Corp.
LUMMI INDIAN RESERVATION
SOUTH BELLINGHAM
Post Pt.
Point Frances
LUMMI I.
Governors Pt
SAMISH I.
GUEMES I.
Samish R.
20
21
24
25
26
27
28
28.5
29
LEGEND
Mean lower low water
—20— Surface salinity (‰)
1/2 0
NAUTICAL MILES

FIGURE 7-4. Average surface salinity in Bellingham Bay--data from University of Washington study of November 1959 - November 1961.

of SWL in the upper part of Bellingham Bay (north of a line between Point Francis and Post Point) indicate that 60% of the mill's waste is contained within 10 feet of the surface and about 90% is contained within 20 feet of the surface. For the whole study area, these estimates are 50% and 70%, respectively. Of importance, then, the surface layer of the study area makes available only a small portion--about 30%--of the total volume of Bellingham-Samish Bays for the assimilation of Georgia-Pacific wastes. Except near the mill (primarily in Bellingham Harbor), waters deeper than 20 feet possess low SWL concentrations (see Figure 7-6); hence, they are little affected by mill wastes.

Vertical Waste Distribution. The vertical distribution of Georgia-Pacific wastes is shown in Figure 7-5 by vertical sections of average, maximum, and minimum SWL concentrations at four stations in the study area (note the differences in the SWL-concentration scales). Vertical waste distribution is shown also by the vertical section of average SWL along a mid-bay transect (Figure 7-6A) and by the vertical composite of maximum SWL observations along the same transect (Figure 7-6B). These figures show the general confinement of dispersed mill wastes in the surface 20 feet of water and the near-absence of these wastes in deeper waters (SWL values greater than 5 ppm are considered positive measures of mill wastes; see article, "Flushing of Wastes During Mill Closure", page 53).

Horizontal Waste Distribution. The horizontal distribution of Georgia-Pacific wastes is shown in Figure 7-7 by the pattern of average surface SWL in the study area. Note that mill wastes spread

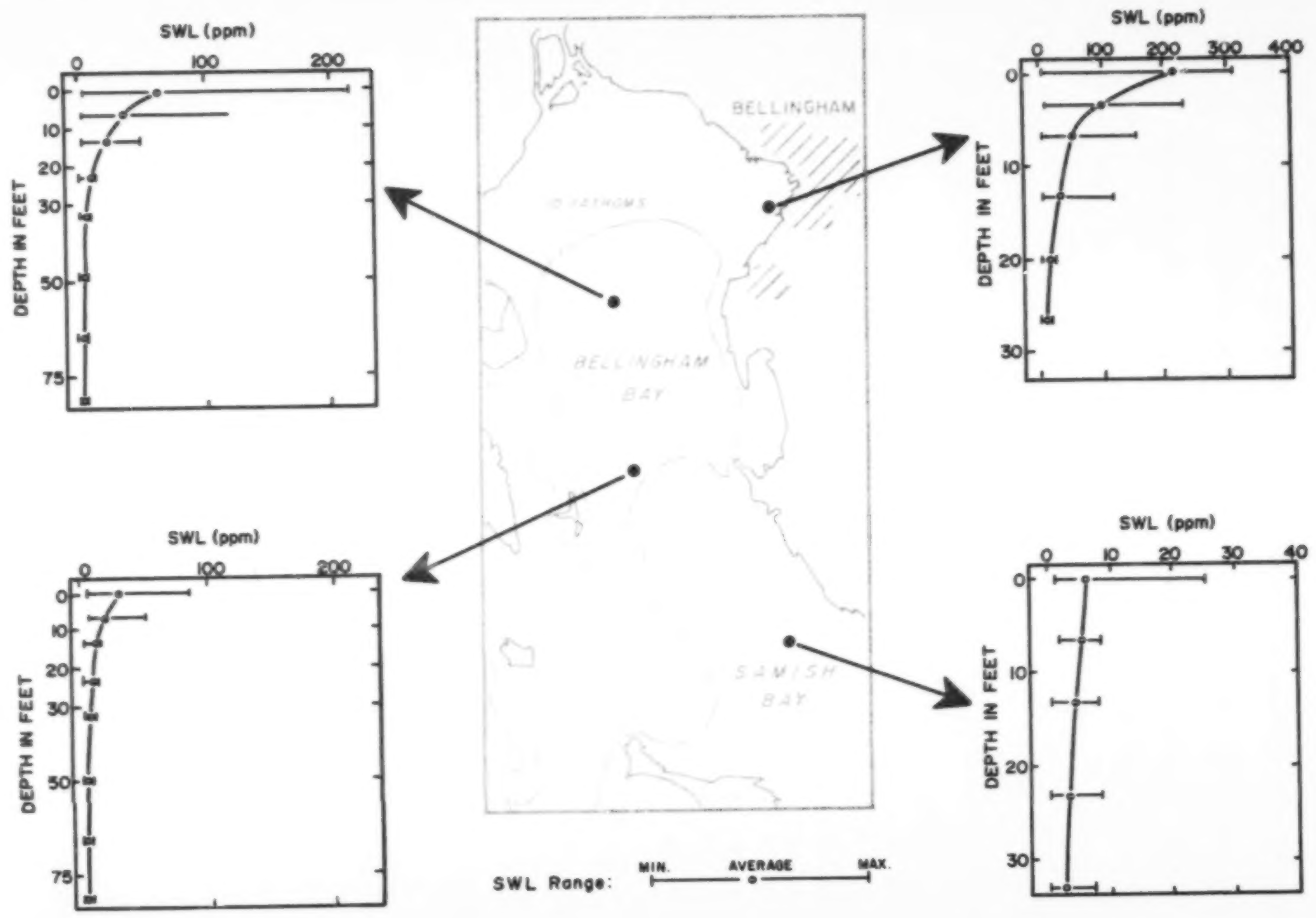


FIGURE 7-5. Vertical distribution of average, maximum, and minimum SWL concentrations at four stations in the Bellingham study area--data from the University of Washington study of November 1959-November 1961.

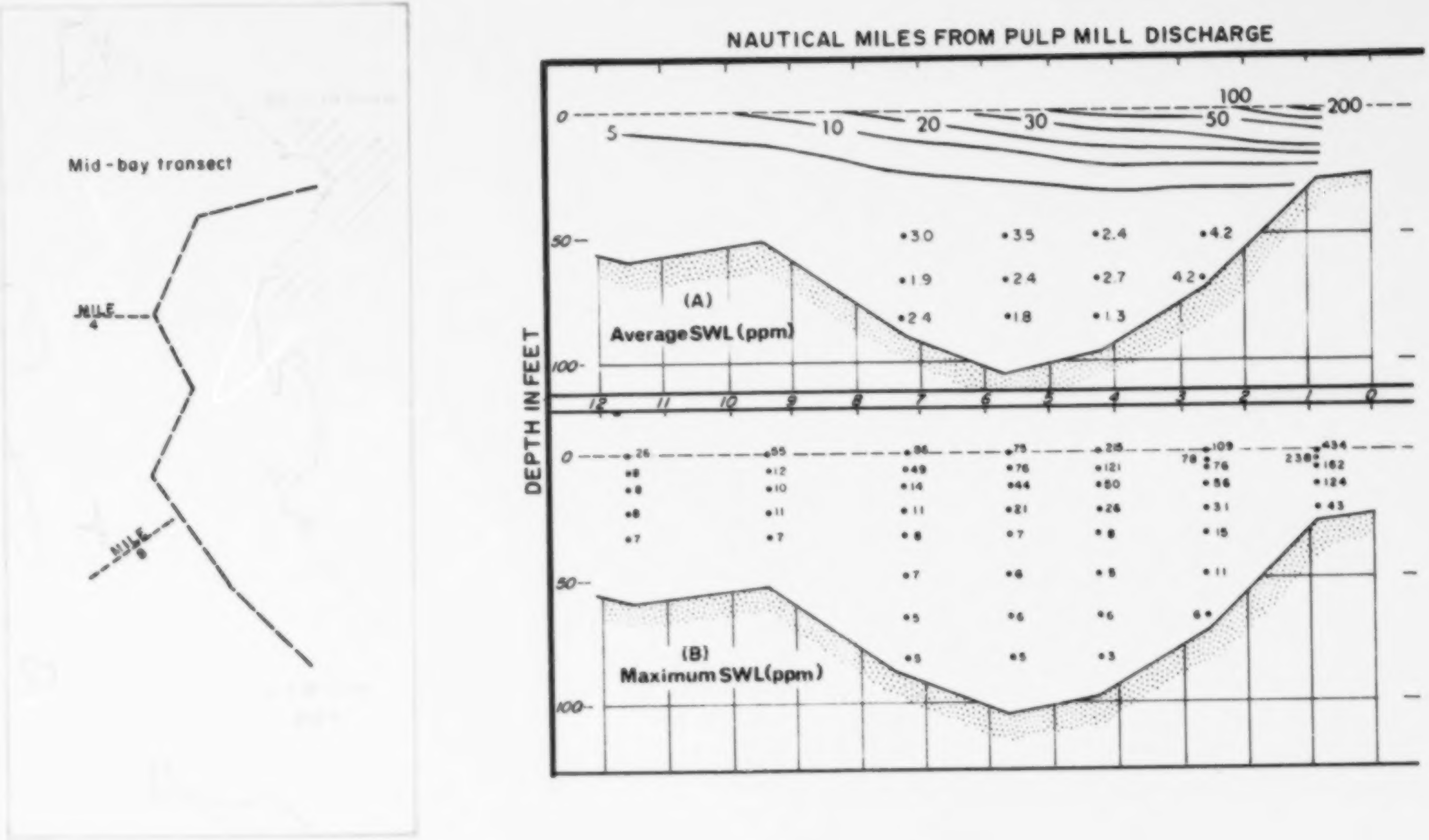


FIGURE 7-6. (A) Vertical distribution of average SWL and (B) Composite of maximum observed SWL along a mid-bay transect in the Bellingham study area--data from the University of Washington study, November 1959 - November 1961.

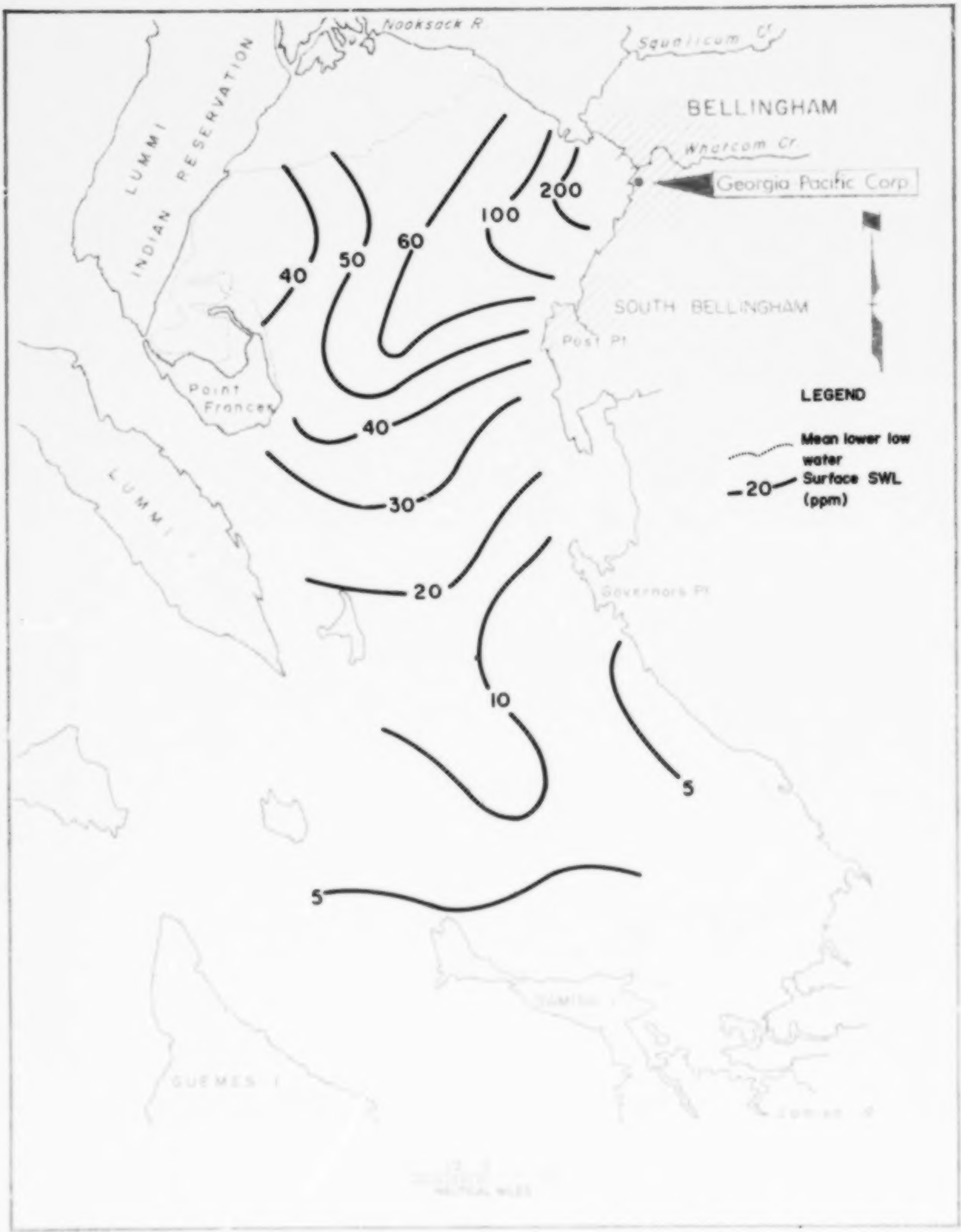

Nooksack R.
Squalicum Cr.
BELLINGHAM
Whatcom Cr.
Georgia Pacific Corp.
LUMMI INDIAN RESERVATION
200
100
60
50
40
40
SOUTH BELLINGHAM
Post Pt
Point Frances
40
30
20
LUMMI
Governors Pt
10
5
5
GUEMES I
SAMISH I
LEGEND
Mean lower low water
20 Surface SWL (ppm)

FIGURE 7-7. Average surface SWL in the Bellingham study area--data from the University of Washington study of November 1959 - November 1961.

throughout the study area, including into Samish Bay. The horizontal distribution of maximum observed concentrations of SWL is shown in Figure 7-8. Note that most maxima greatly exceed average concentrations.

Surface Circulation. Net transport (long-term movement) of surface waters in the study area is seaward and out of the area. This transport is driven by the inflows of freshwater. Consequently, in the upper part of Bellingham Bay, net surface-water movement carries Nooksack River water and Georgia-Pacific wastes southward and produces the patterns of average surface salinity and average surface SWL shown in Figures 7-4 and 7-7, respectively. Surface transport out of the study area is shown in Figure 7-9. This information, derived from U.S.C.&G.S. current meter data, shows surface water movement primarily into Rosario Strait but also into Padilla Bay; consequently, some dispersed wastes from the Georgia-Pacific mill are carried into the Anacortes area.

Short-term surface circulation is variable and results primarily from the variable actions of tides, winds, and combinations thereof. Strong southerly winds tend to hold Nooksack River water in the northern part of Bellingham Bay, causing it to spread into Bellingham Harbor and contiguous waters. Northerly winds or the absence of winds allow southward movement of River outflows. Consequently, short-term patterns of surface salinity show much variation.

Short-term patterns of surface SWL also show hour-to-hour and day-to-day changes, and they describe wide fluctuation in the transport and dispersion of Georgia-Pacific wastes. As a result, SWL

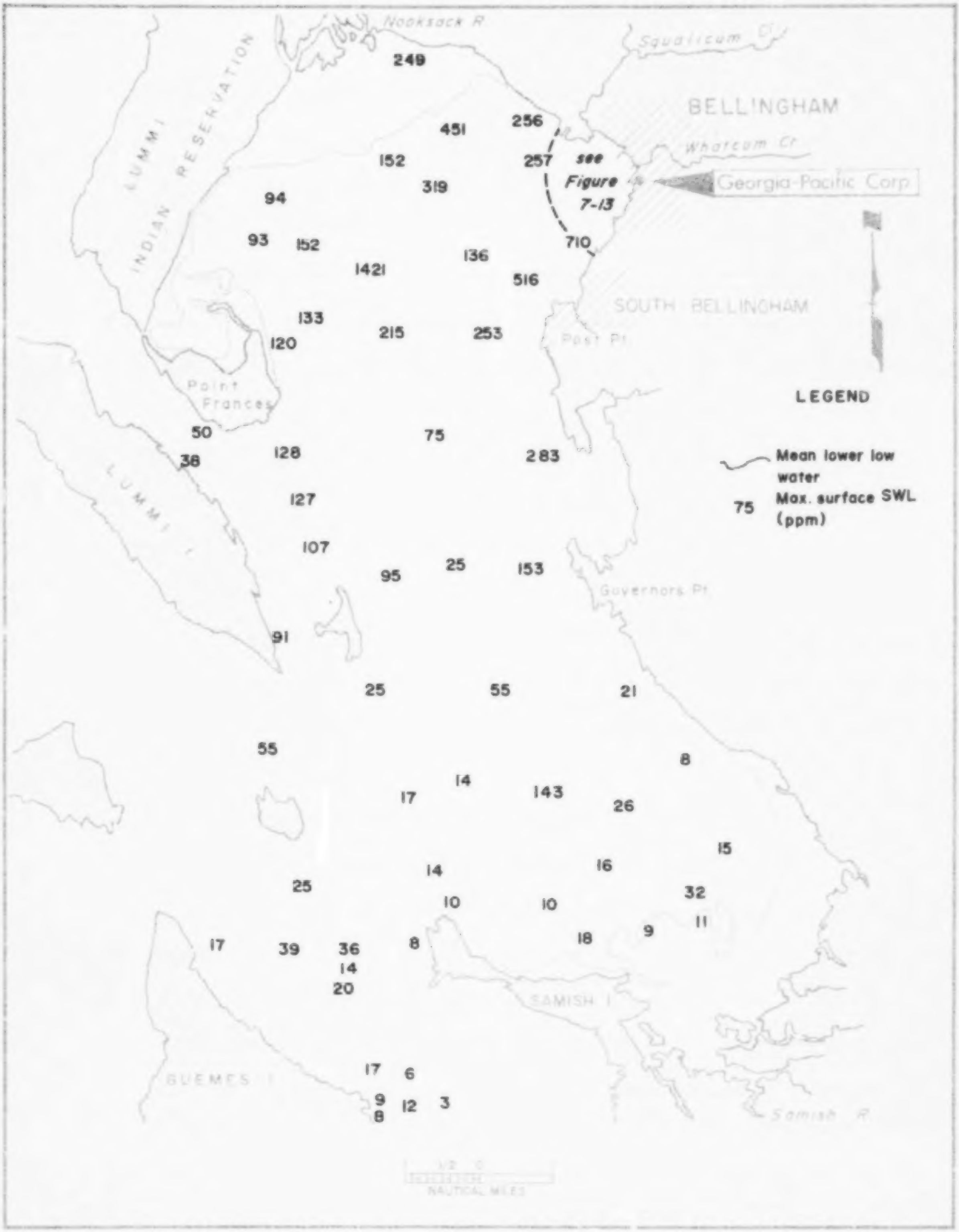

Nooksack R
Squalicum Cr
249
BELLINGHAM
451
256
Whatcom Cr
152
257
see Figure 7-13
Georgia-Pacific Corp
319
94
LUMMI INDIAN RESERVATION
710
93
152
1421
136
516
SOUTH BELLINGHAM
133
120
215
253
Post Pt
Point Frances
LEGEND
50
38
75
128
283
Mean lower low water
LUMMI I
127
75
Max. surface SWL (ppm)
107
95
25
153
Governors Pt
91
25
55
21
55
8
14
17
143
26
15
14
16
25
10
10
32
11
9
18
17
39
36
14
20
8
SAMISH I
17
6
GUEMES I
9
8
12
3
Samish R
1/2 0
NAUTICAL MILES

FIGURE 7-8. Maximum observations of surface SWL in the Bellingham study area--data from University of Washington studies (11/59-11/61), Washington Department of Fisheries studies (9/56-9/59), Washington Pollution Control Commission studies (1957-58), and certain Project studies (10/62-12/64).

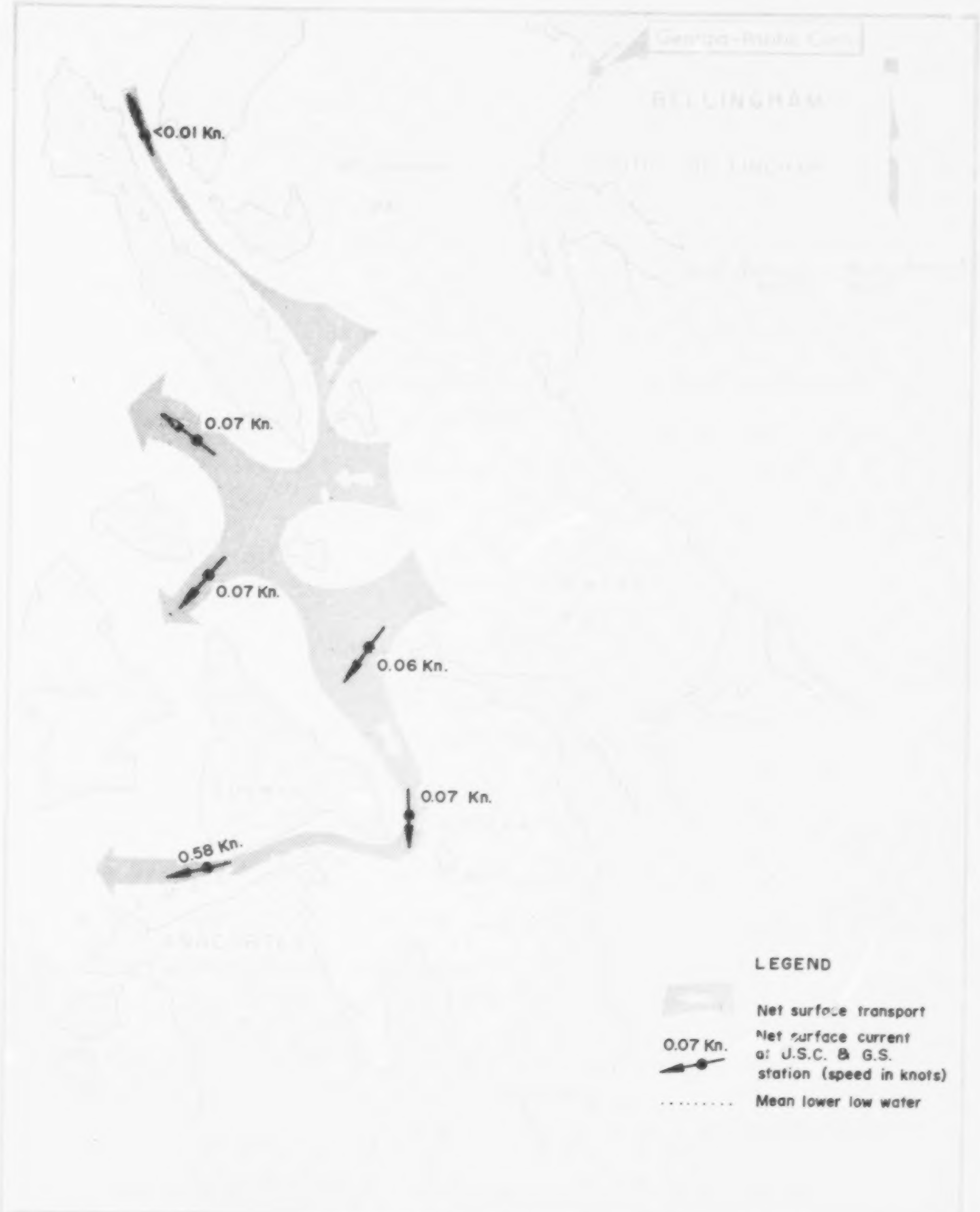

BELLINGHAM
<0.01 Kn.
0.07 Kn.
0.07 Kn.
0.06 Kn.
0.07 Kn.
0.58 Kn.
ANACORTES
LEGEND
Net surface transport
0.07 Kn.
Net surface current at U.S.C. & G.S. station (speed in knots)
Mean lower low water

FIGURE 7-9. Net surface circulation pattern and net surface currents in the Bellingham-Anacortes area; data from U.S.C.&G.S. current meter studies of 1964-65.

concentrations much higher than average values are found in all parts of the study area; compare Figure 7-8 with Figure 7-7.

Flushing of Wastes During Mill Closure. The Georgia-Pacific mill was closed by a labor strike and little or no wastes were discharged between November 12 and 25, 1964. From water quality data collected in special cruises during and after this period, the surface SWL patterns on November 18 and 25, and December 1 (Figures 7-10B, C, and D, respectively) were derived. Figure 7-10A shows the average surface SWL pattern (same as Figure 7-7) for the November 1959-November 1961 period. Note the following features:

Figure 7-10B -- after 6 days of closure, waste concentrations throughout the study area were considerably reduced from average values.

Figure 7-10C -- after 13 days of closure, nearly all mill wastes had been flushed from the study area, and except in the vicinity of the mill, background SWL levels of 2 to 5 ppm prevailed.

Figure 7-10D -- six days after resumption of operations, mill-waste concentrations throughout the study area were returning to levels observed under normal mill operation.

These results evidence an estimated total flushing time of 14 to 17 days for the Bellingham-Samish Bay system. That is, for the freshwater discharges (which influence the length of flushing time) prevailing during the closure period, the Bay-system would have required from

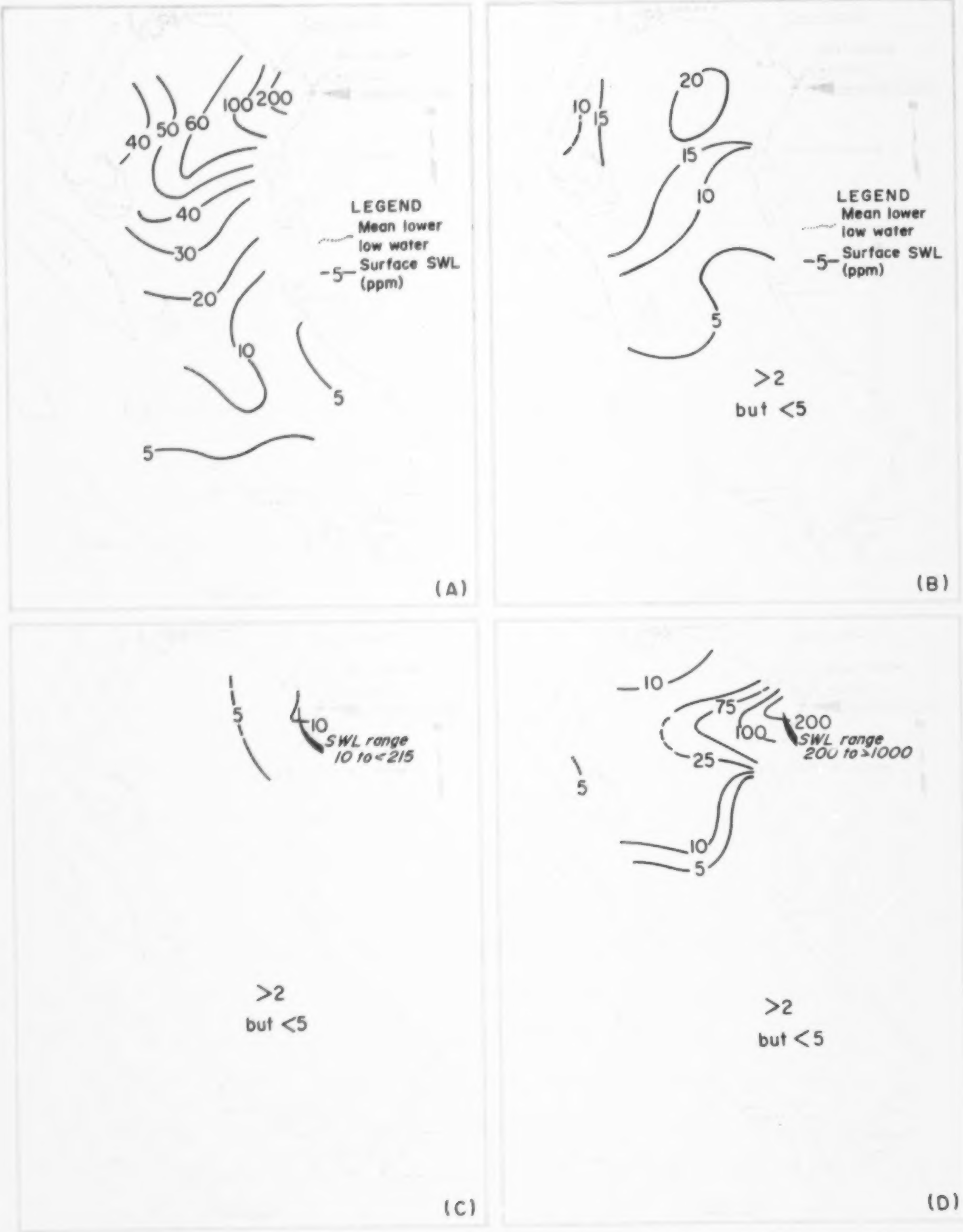

40
50
60
100
200
40
30
20
10
5
5
LEGEND
Mean lower low water
-5- Surface SWL (ppm)
(A)
10
15
20
15
10
5
LEGEND
Mean lower low water
-5- Surface SWL (ppm)
>2 but <5
(B)
5
10
SWL range 10 to <215
>2 but <5
(C)
10
75
100
200
SWL range 200 to >1000
25
5
10
5
>2 but <5
(D)

FIGURE 7-10. Patterns of surface SWL: (A) average over the period November 1959-November 1961 (B) observed on November 18, 1964; (C) observed on November 25, 1964. and (D) observed on December 1, 1964.

14-17 days to flush itself essentially free (below 5 ppm) of Georgia-Pacific mill wastes. This estimate falls within the range of average flushing time estimates (3.2 to 78.0 days depending on freshwater discharges) based on salinity relationships computed by Westley (1960).

Of further importance are the very low background levels of apparent-SWL observed in the study area during the closure period. On November 25, when flushing of wastes from the area was nearly completed, SWL concentrations at 17 stations outside (south) of the 5 ppm isopleth (Figure 7-10C) averaged 1.1 ppm and had a median of 1 ppm. Even on December 1, SWL concentrations at 20 stations outside the 5 ppm isopleth (Figure 7-10D) averaged 2.8 ppm and had a median of 3 ppm; and on November 18, at 15 such stations (Figure 7-10B) they averaged 3.3 ppm and had a median of 3 ppm. These data clearly show that in the absence of Georgia-Pacific waste discharges background levels of apparent-SWL throughout the study area would be less than 3 ppm and would probably be 1 ppm. Consequently, the background level of 5 ppm used in this part of the report is definitely a conservative value.

Water Quality in Bellingham-Samish Bays. In the outer waters of Bellingham Bay and in Samish Bay (*i.e.*, all study area waters except Bellingham Harbor), the principal water quality effect caused by Georgia-Pacific wastes is the appearance of dilute concentrations of sulfite waste liquors in the surface waters. Figure 7-7 shows that surface waters over about half of the study area are affected by average SWL concentrations of 20 ppm or greater and the remainder of the surface waters are influenced by average SWL concentrations ranging from background levels (less than 5 ppm) to 20 ppm. More important, Figure 7-8 shows that maximum surface SWL concentrations reach levels of 100 to 1,400 ppm in Bellingham Bay and levels of 10 to 140 ppm in Samish Bay. The extent to which these concentrations are toxic to marine life is related in the following sections.

Other water quality properties in the outer-Bay waters are only slightly affected by mill wastes. Figure 7-11 shows that surface DO, pH, and water transparency are slightly reduced in the area of high SWL concentrations in the upper part of Bellingham Bay.

Water Quality in Bellingham Harbor. Contrary to the situation in the outer-Bay waters, discharges of mill wastes produce extremely high concentrations of sulfite waste liquors and considerable degradation of water quality in Bellingham Harbor. This is illustrated by the observed patterns of surface SWL, DO, and pH shown in Figure 7-12. Note the high concentrations of SWL, varying from 200 ppm to over 6,000 ppm; the depressed levels of DO, down to 4 and 5 mg/l; and the low values of pH.

Extreme and, oftentimes, rapid changes in Harbor water quality also were observed. These resulted from the variable actions of winds and tides which considerably influence Harbor water circulation and the immediate transport and dispersion of near-surface-discharged mill wastes. Consequently, maximum and minimum values of SWL, DO, and pH typical of those shown in Figure 7-13 were frequently recorded. Note the extremes in SWL concentrations from values less than 100 ppm to

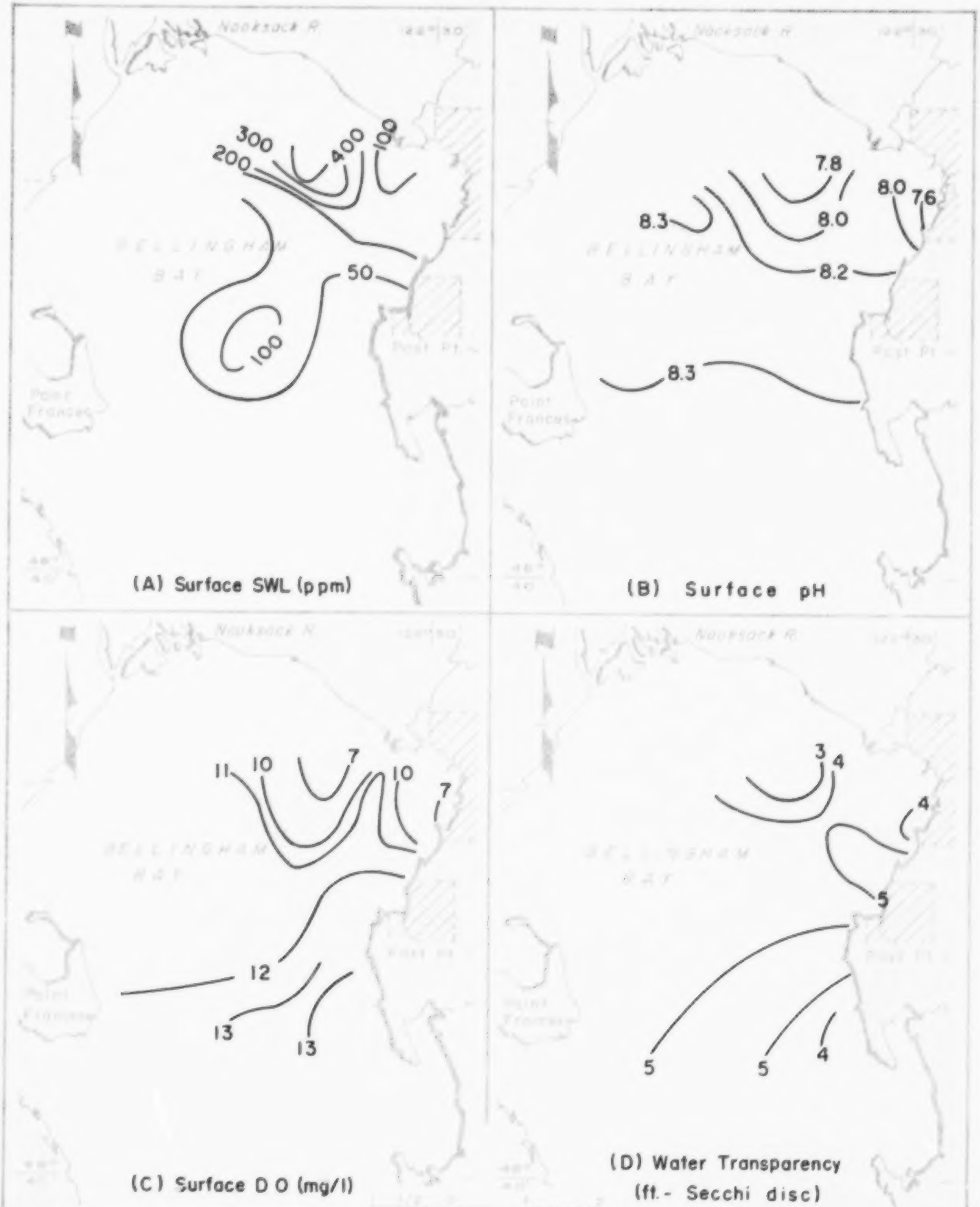
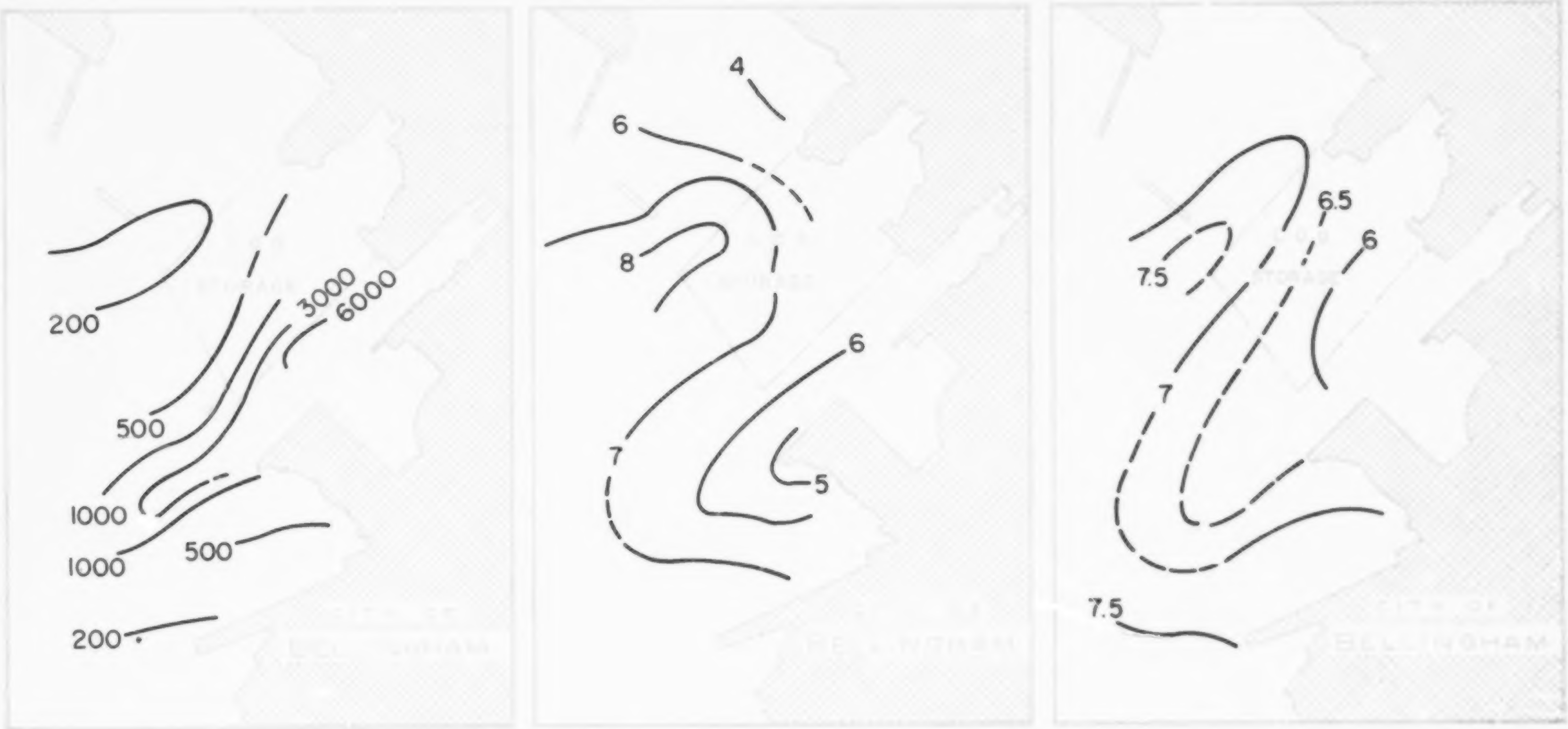

Nooksack R.
BELLINGHAM BAY
Post Pt.
Point Frances
300
200
400
100
50
100
(A) Surface SWL (ppm)
7.8
8.0
7.6
8.3
8.0
8.2
8.3
(B) Surface pH
11
10
7
10
7
12
13
13
(C) Surface D O (mg/l)
3
4
4
5
5
5
4
(D) Water Transparency
(ft.- Secchi disc)
NAUTICAL MILES

FIGURE 7-11. Patterns of (A) surface SWL, (B) surface pH, (C) surface DO, and (D) water-transparency observed in Bellingham Bay on July 3, 1963.

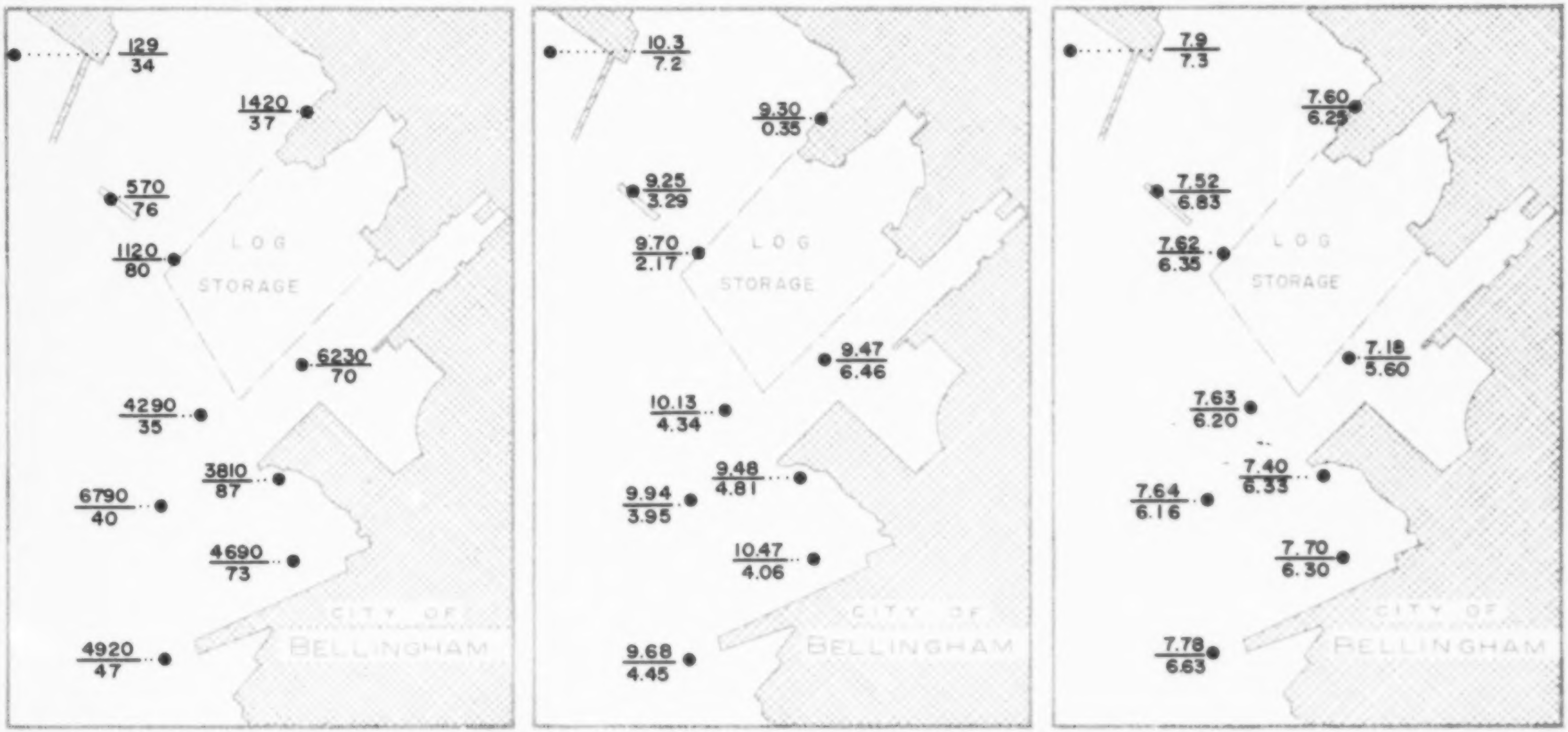

200
500
1000
1000
500
200
3000
6000
6
4
8
6
7
5
7.5
6.5
6
7
7.5
STORAGE
CITY OF
BELLINGHAM

(A) Surface SWL (ppm)

(B) Surface DO (mg/l)

(C) Surface pH

FIGURE 7-12. Patterns of (A) surface SWL, (B) surface DO, and (C) surface pH observed in Bellingham Harbor on May 26, 1964.


129/34
1420/37
570/76
1120/80
LOG STORAGE
6230/70
4290/35
3810/87
6790/40
4690/73
4920/47
CITY OF BELLINGHAM
10.3/7.2
9.30/0.35
9.25/3.29
9.70/2.17
LOG STORAGE
9.47/6.46
10.13/4.34
9.48/4.81
9.94/3.95
10.47/4.06
9.68/4.45
CITY OF BELLINGHAM
7.9/7.3
7.60/6.25
7.52/6.83
7.62/6.35
LOG STORAGE
7.18/5.60
7.63/6.20
7.40/6.33
7.64/6.16
7.70/6.30
7.78/6.63
CITY OF BELLINGHAM

(A) SWL (ppm)

(B) DO (mg/l)

(C) pH

FIGURE 7-13. Maximum and minimum observations of (A) SWL, (B) DO, and (C) pH in Bellingham Harbor during May 26-29, 1964.

values greater than 6,000 ppm; the extremes in DO, from concentrations less than 4 mg/l to those greater than 9 mg/l; and the extremes in pH, from values near 6 to values greater than 7. As indicated, the Harbor is alternately affected by waters of good or acceptable quality and waters of poor or degraded quality.

Bottom Deposits. Natural sediments in Bellingham Bay generally consist of homogeneous, silt-clay muds containing about 10% sand. In many cases, this base formation is covered by a layer of very fine, flocculated material, described as the oxidized layer because of its brownish appearance (Sternberg, 1961). In Whatcom Waterway and contiguous areas of Bellingham Harbor, however, this oxidized layer is absent and the base formation is overlaid with a sludge deposit--an oxygen-deficient layer of decomposing organic material composed, primarily, of settled, volatile suspended solids discharged by the Georgia-Pacific pulp and board mill (see Table 6-1) and the Georgia-Pacific paper mill (see Table 6-2). This sludge is characterized by its black color, its strong hydrogen-sulfide odor, its content of wood chips and considerable amount of wood fiber, and its relatively high volatile solids content (Figure 7-14B). Although the depth of this deposit was measured only in Whatcom Waterway, sludge probably accumulates in adjacent areas where docks (to the east) and log storage (to the west) precluded sampling. Sludge thickness in the Waterway varied from zero at the entrance to 21 inches at the inner end (Figure 7-14A), and the sludge volume in the Waterway was estimated to be about 42,000 cu. yds. To maintain navigability, the Waterway is periodically dredged; hence these thicknesses and volume values do change.

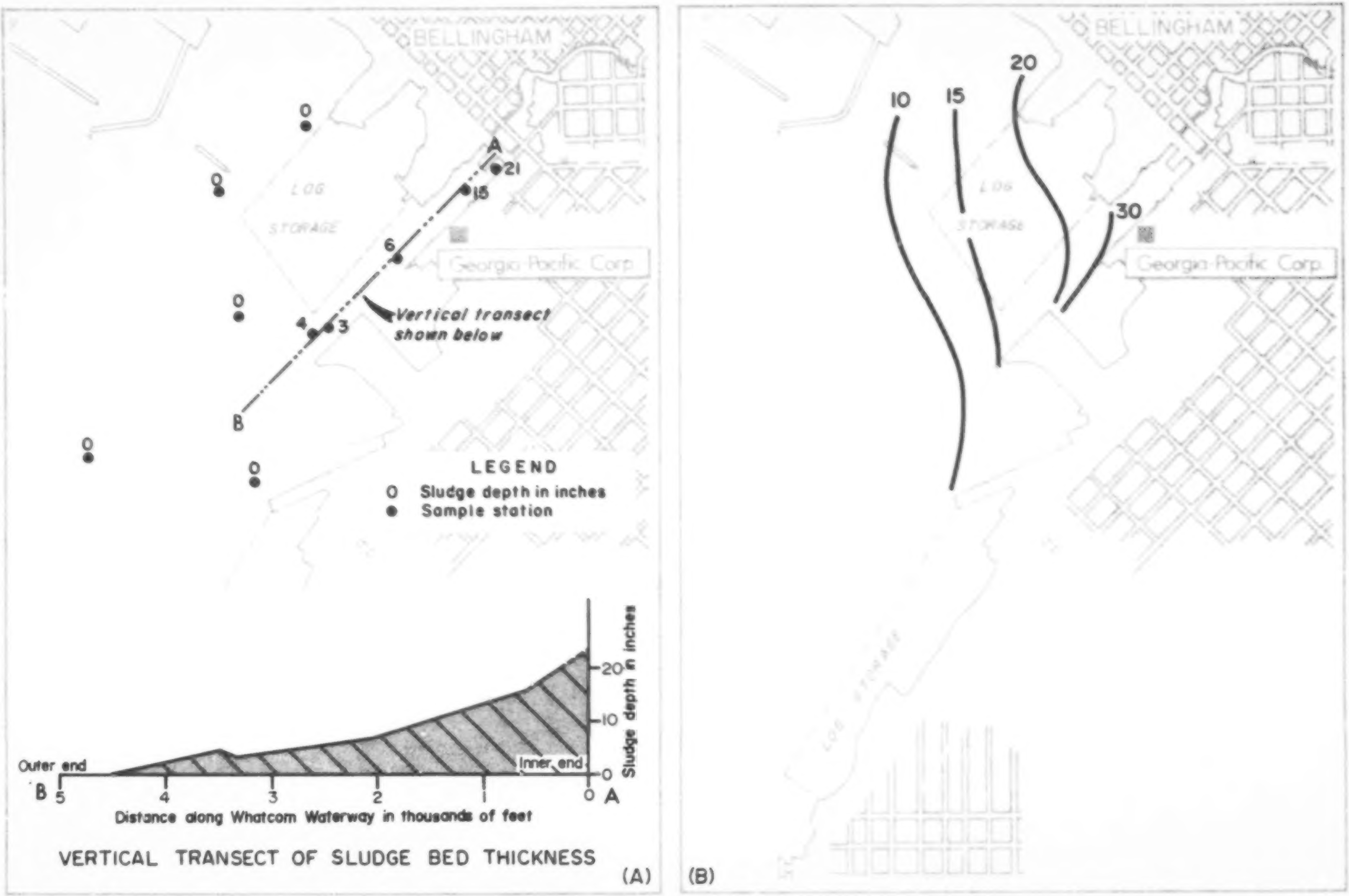
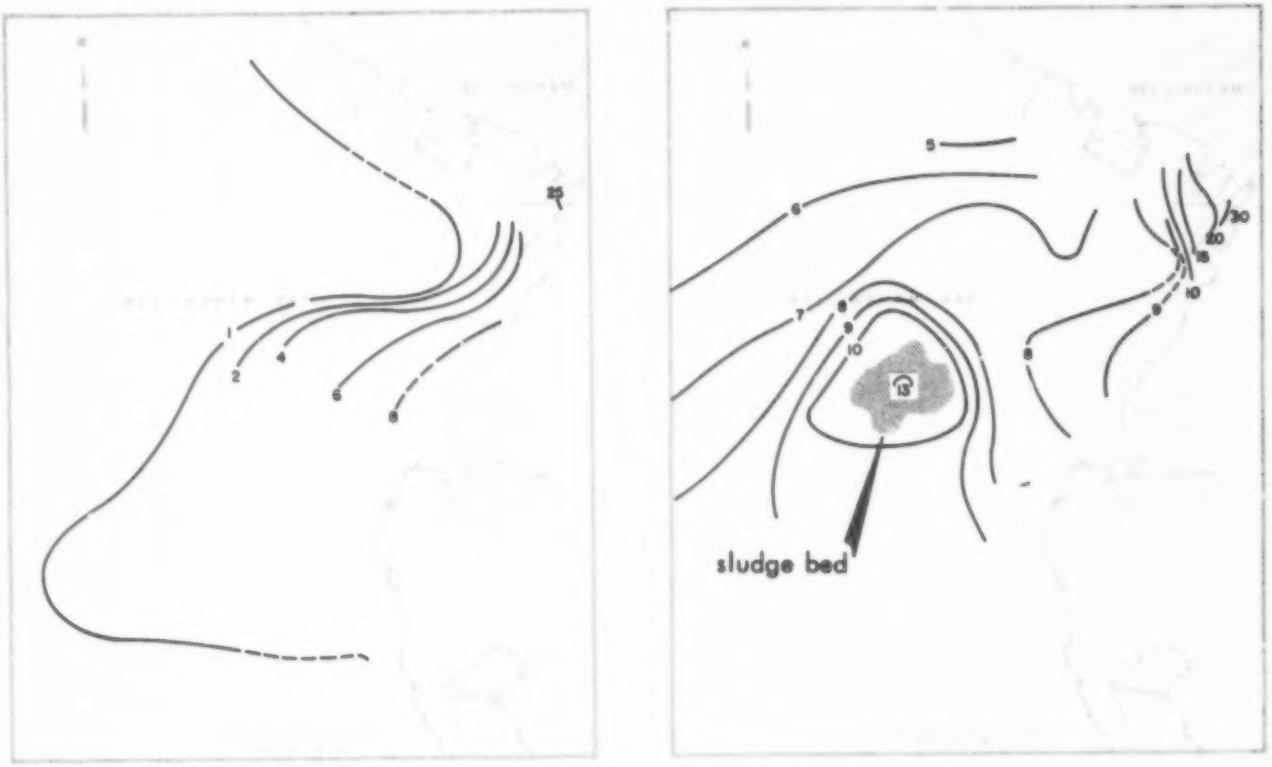

BELLINGHAM
LOG STORAGE
Georgia-Pacific Corp.
A
B
0
0
0
0
0
21
15
6
4
3
Vertical transect shown below
LEGEND
0 Sludge depth in inches
● Sample station
Outer end
Inner end
B 5
4
3
2
1
0 A
0
10
20
Sludge depth in inches
Distance along Whatcom Waterway in thousands of feet
VERTICAL TRANSECT OF SLUDGE BED THICKNESS
(A)
(B)
BELLINGHAM
10
15
20
30
LOG STORAGE
Georgia-Pacific Corp.
LOG STORAGE

FIGURE 7-14. Sludge deposits in Whatcom Waterway and Bellingham Harbor: (A) sludge thickness, and (B) percent volatile solids content of sludge.

In addition to the sludge in the Waterway, wood chips and bark fragments are found in the sediments throughout the northern part of Bellingham Bay (Figure 7-15A). In part, this material is torn bark from log rafts and spillage from chip barges towed through the area. However, it appears that a larger part comes from the disposal of accumulated sludge periodically dredged from the Waterway at Georgia-Pacific's chip-barge unloading facility. Barge loads of dredged material have been observed being dumped off of Post Point, and the area of disposal is the same as the area where anomalous percent volatile solids were found in bottom sediment samples (Figure 7-15B).

DISCUSSION

Because the Bellingham-Samish Bay system is influenced by a relatively stable surface layer of less-than-seawater salinity, by weak and variable circulation, and by protracted flushing, wastes discharged by the Georgia-Pacific mill are not provided sufficient dilution to avert their affecting water quality. In Bellingham Harbor, the area of disposal and immediate dispersion, the large volume of strong pulping and papermaking wastes discharged cause substantial degradation of water quality and accumulation of settleable solids. The Harbor does not have the assimilative or flushing capacity to accept these wastes without the consequence of serious pollution. In the remaining part of the study area, outer Bellingham Bay and Samish Bay, the amount of strong pulping wastes emitted--sulfite waste liquors and alcohol plant wastes--far exceed that which can be dispersed


1
2
4
6
8
25
5
6
7
8
9
10
13
8
9
10
15
20
30
sludge bed

(A)

(B)

FIGURE 7-15. Characteristics of bottom sediments in Bellingham Harbor and contiguous parts of Bellingham Bay: (A) percent wood fraction--chips and fragments--in the sediments (Sternberg, 1964), and (B) percent volatile solids in the sediments.

and diluted to non-damaging concentrations within the limited volume available in the surface-water layer. Summarily, the Bellingham-Samish Bay system does not have the assimilative capacity to handle the types and amounts of wastes presently discharged by the Georgia-Pacific complex--both the pulp and board mill, and the paper mill.

The following sections describe the types and degrees of damage to marine life presently occurring in the study area, and each section delineates the water quality criteria that are prerequisite for preventing such damage. In preview, however, these criteria require, principally, the reduction in SWL or pulping waste concentrations throughout the study area, the maintenance of tolerable DO and pH levels in the Harbor, and the prevention of solids accumulation in the Harbor. Of importance here, these criteria, most probably, will have to be met by means of waste treatment for the removal of dissolved solids and biochemical oxygen demand from pulping wastes and the removal of suspended solids from papermaking, barking, and other solids-bearing waste streams. Relocation (within limits) or modification of present outfall sewers for the disposal of present loads of untreated wastes will not accomplish compliance with these criteria because of the above-mentioned hydraulic characteristics of the Bay system. The system is too shallow for accomplishing deep-water dispersion that would preclude adverse effects on surface water quality. Furthermore, flushing is too weak and water circulation is too variable in most parts of the study area to effect rapid dispersion and transport of wastes from reasonably located disposal sites. Solids accumulation also would occur at most reasonably located disposal sites. In conclusion, the Bellingham-Samish

Bay system is hydraulically unsuited as a receiving body of water for the disposal of the large volume of partially treated wastes generated by the Georgia-Pacific mills. Therefore, abatement of the existing pollution of these waters must proceed through adequate treatment of the mills' wastes.

8. JUVENILE SALMON

The several tributary streams of the Bellingham area are spawning and rearing grounds for the anadromous salmonids: Chinook, silver, chum, and pink salmon; and steelhead, sea-run cutthroat, and dolly varden trout. The Nooksack River contributes to a large commercial fishery in Bellingham Bay, and the Samish River supports a significant sport fishery. Squalicum, Padden, and Chuckanut Creeks are lesser producers.

Annually, from March through July, juvenile (one year old or less) salmon and trout migrate downstream and enter estuarine waters. Pink, chum, and fall chinook salmon begin migrating soon after hatching, and they enter Bellingham Bay as fry (about 1 to 2 inches in length). In the Bay they usually seek nearshore waters for food and protection; hence their seaward movement is along the shoreline until they are large enough to move into offshore waters. Being weak swimmers, however, some of these fry are occasionally swept by strong river discharges directly into offshore waters, and their subsequent movement to shoreline waters is delayed, if accomplished at all. Silver and spring chinook salmon, and anadromous trout spend at least a year after hatching in the rearing stream before migrating downriver. They enter the estuary as fingerlings (from about 3 to 12 inches in length). Since they are strong swimmers, they usually move directly into offshore waters, but spring chinook may spend a short time in nearshore waters.

STUDIES

Numbers of salmon fry and some fingerlings from the Nooksack River and Squalicum Creek migrate through Bellingham Harbor and adjacent waters. Since the Harbor is considerably polluted by Georgia-Pacific wastes (see Figures 7-12 and 7-13), and because juvenile salmon can be adversely affected by sulfite waste liquor (Williams, et al., 1953; Washington Department of Fisheries, 1960) and by reduced dissolved oxygen, low pH, and concentrations of hydrogen sulfide, ammonia, other toxicants, and combinations thereof (McKee and Wolf, 1963), juvenile salmon migration-occurrence and bioassay studies were conducted in Bellingham Harbor.

Migration Occurrence Studies. From April through June 1963, the Fisheries Research Institute (FRI) of the University of Washington sampled juvenile salmon populations in Bellingham Bay to obtain information on their seaward migration and distribution in the Bay. This study, reported by Tyler (1964), included 75 near-surface tows in the offshore sampling areas shown in Figure 8-1A.

The Project conducted four beam-trawl studies in the northern part of Bellingham Bay during May 1964. In each study, 3 to 6 five-minute tows (57 tows in all) were made along each of the three transects shown in Figure 8-1B.

During April, May, and June 1964, the Project sampled fish populations in Bellingham Harbor to determine occurrence of young salmon in these waters. Sampling was accomplished by running a mobile fishtrap along the 22 transects shown in Figure 8-2. A total of 226 runs were made over 13 sampling days.

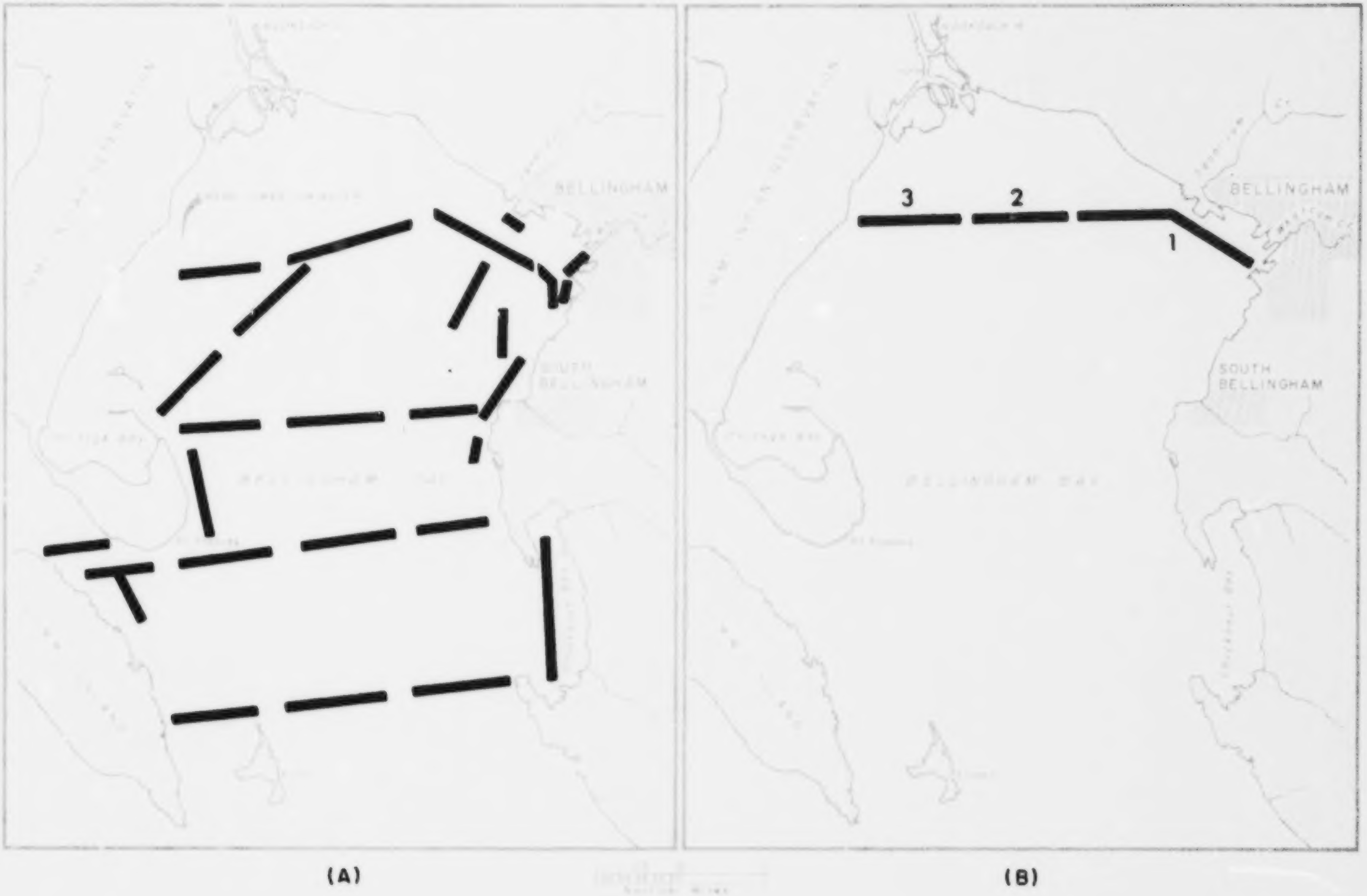
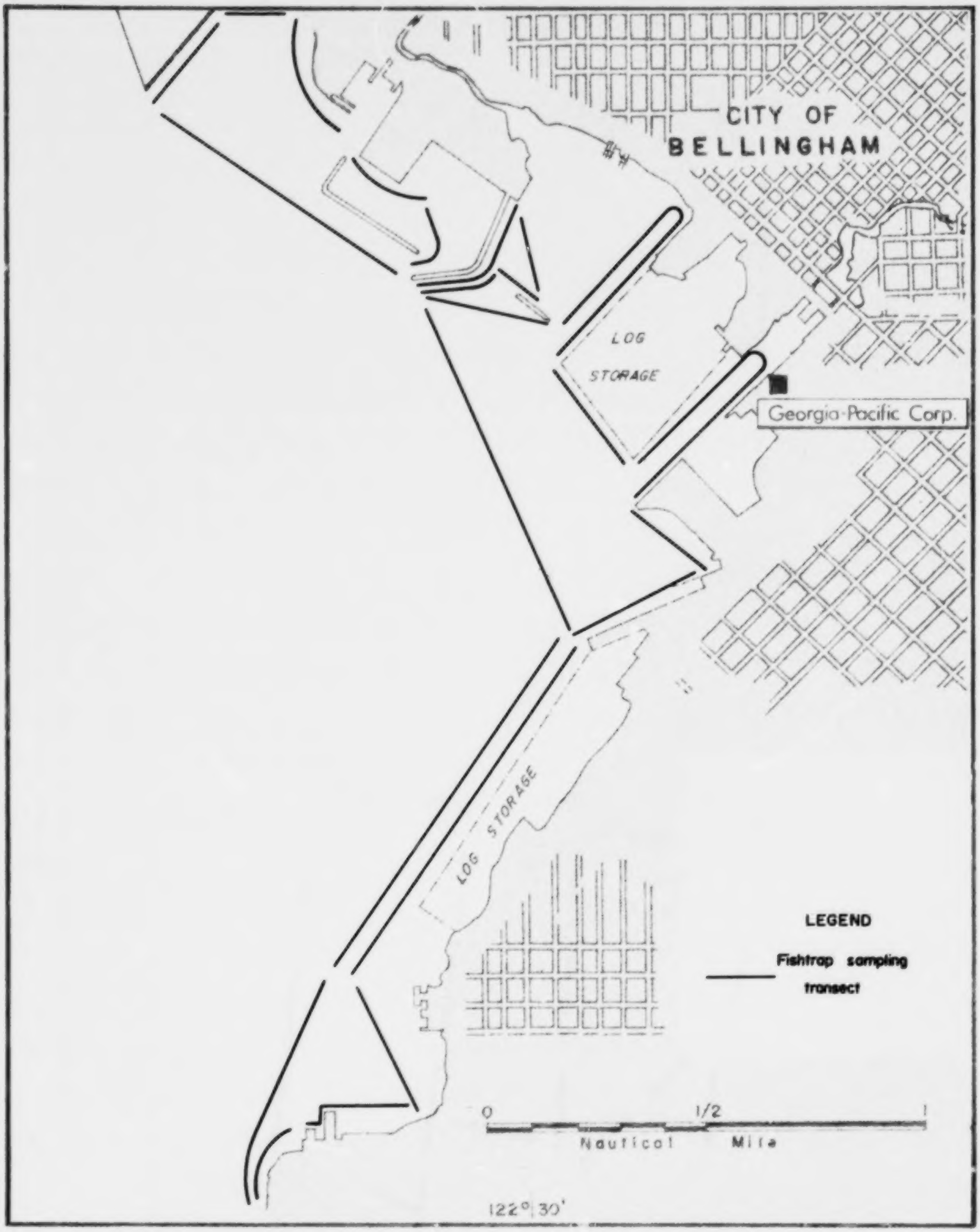

BELLINGHAM
SOUTH BELLINGHAM
BELLINGHAM BAY
3
2
1
(A)
(B)

FIGURE 8-1. Areas of Bellingham Bay sampled for juvenile salmon: (A) FRI townet sampling areas during April-June 1963, and (B) Project beam-trawl sampling transects during May 1964.



CITY OF BELLINGHAM
LOG STORAGE
Georgia-Pacific Corp.
LOG STORAGE
LEGEND
Fishtrap sampling transect
0
1/2
1
Nautical Mile
122°|30'

FIGURE 8-2. Fishtrap sampling transects in Bellingham Harbor, April-June 1964.

Bioassay Studies. The Project conducted bioassay studies in Bellingham Harbor and contiguous nearshore waters during June 1963, May 1964, and May and June 1965. The 1963-64 investigations were *in situ* studies to delineate areas where significant juvenile mortalities could occur. On eleven dates, live boxes, each containing ten chum salmon fry, were placed at selected stations for exposure periods of 4 or 24 hours. Usually, these boxes were placed at eight, nine, or ten of the seventeen stations shown in Figure 8-8. During the exposure period, each box was visited periodically (hourly during the 4-hour periods and at the termination of the 24-hour periods) to observe test fish mortalities and to collect water samples. Wind, weather, and tide stage also were noted. In all, 89 exposure tests were conducted. Twenty-four tests were concluded after four hours' exposure and the remaining 65 were continued for the full twenty-four-hour period.

The 1965 investigation was a modified *in situ* study to examine water quality changes associated with juvenile mortalities. Exposure tests were conducted in two flow-through test chambers on board the R/V HAROLD W. STREETER. These test chambers were constructed to permit continuous observation of test fish reactions and to facilitate frequent water sampling. Test water was continuously pumped (about 2 gpm) from the surface three feet of water at the station occupied. Water was pumped separately to each chamber and was not recirculated. In each test, ten chum salmon fry (average 43.2 mm, standard length) were placed in either one of the test chambers, and their behavior and mortalities were observed and recorded throughout the exposure period. (During several of the tests, a 16-mm movie camera was used to record distress behavior and subsequent mortality.)

Concomitantly with behavioristic observations, samples of test chamber water were taken at three- to fifteen-minute intervals. Twenty tests were conducted at Station B (Figure 8-8). These exposure periods ranged from a few minutes to over 4 hours; those lasting less than 4 hours were terminated by 100% mortality (Table 8-3). Five control tests were conducted at Station A (Figure 8-8). Exposure periods in these tests ranged from about 4 to about 46 hours (Table 8-3).

METHODS

Migration-Occurrence Study Methods. In the FRI townet studies, most tows were made with a 10x20x43-foot net. However, for some of the earliest tows, a net having a 9-foot square opening was employed. Either net was towed through near-surface waters behind two boats. Duration of each tow was about 15 minutes.

A 9x9-foot beam trawl was used in the Project trawl studies. As in the FRI studies, this net was towed through near-surface waters behind two boats, and at the end of each tow, captured fish were counted by species.

The mobile fishtrap used in the Project's Harbor-occurrence studies is shown in Figure 8-3. This device was suspended between two outboard-motor boats and moved through the water such that fish were scooped up by the front funnel section and were carried by the flow of water up the inclined plane and into the rear holding box. A cross-section of water 12 feet wide and 1-1/2 feet deep was sampled. Normal procedure was to run the trap along each transect (Figure 8-2); to record the time of run; and after completion to count, by species, the fish captured.

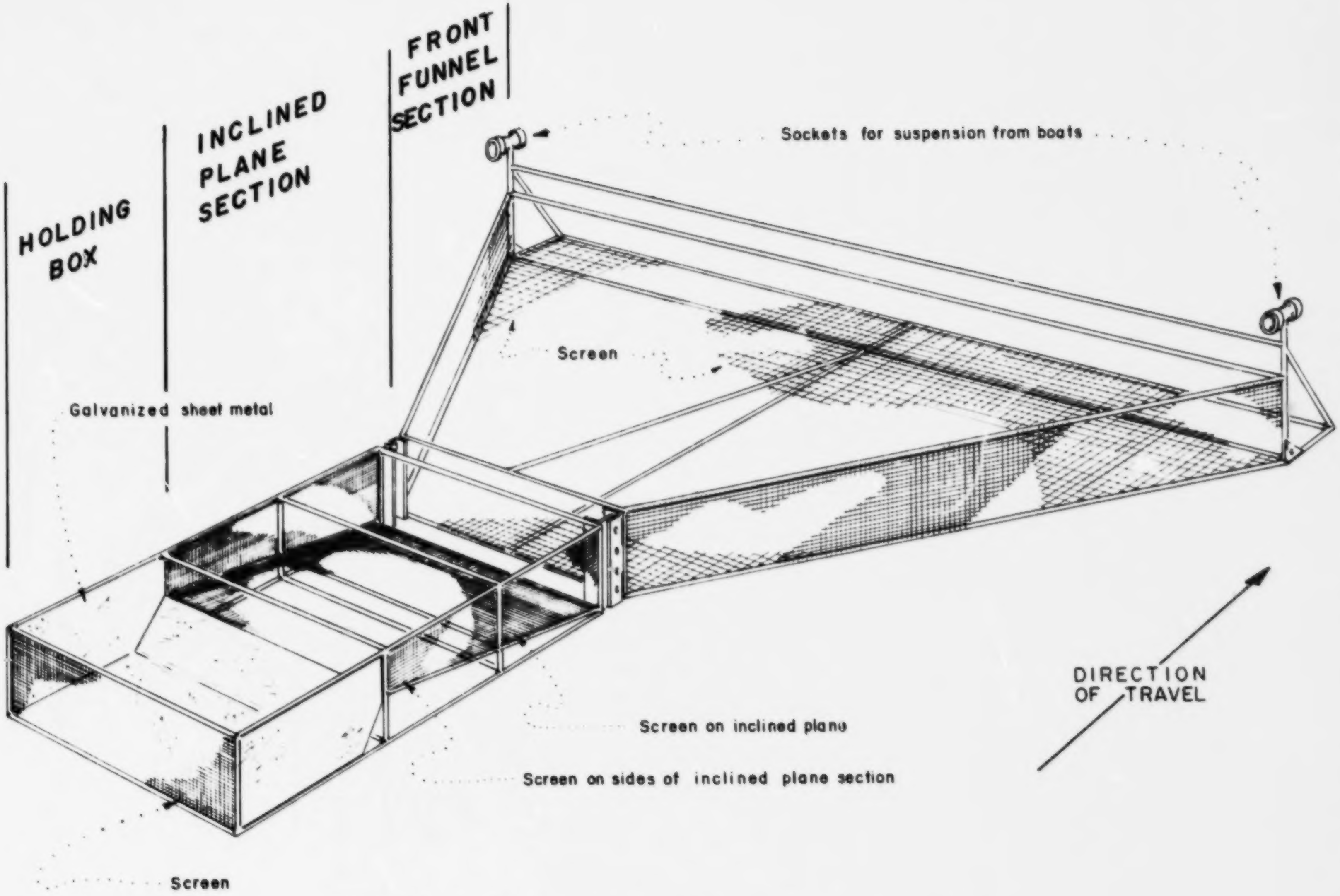

HOLDING BOX
INCLINED PLANE SECTION
FRONT FUNNEL SECTION
Sockets for suspension from boats
Screen
Galvanized sheet metal
Screen on inclined plane
Screen on sides of inclined plane section
Screen
DIRECTION OF TRAVEL

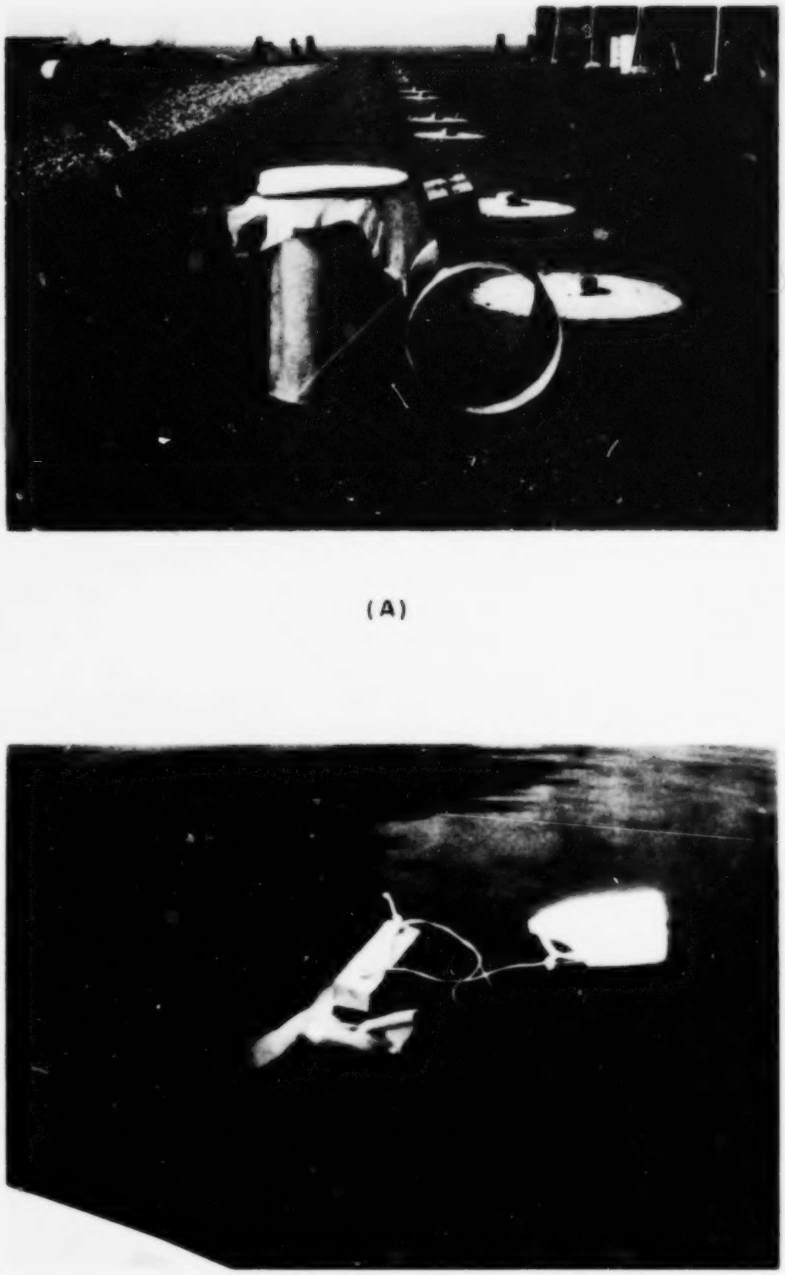
FIGURE 8-3. Mobile fishtrap for sampling juvenile salmon populations.

Bioassay Methods. Test fish used in both the 1963-64 and 1965 studies were outmigrant chum salmon fry captured by various beach-seining techniques in or near the Nooksack River. These fish were kept in a holding box near Control Station 3 (Figure 8-8) for a period of not less than 48 hours prior to use. Only fish in good condition were used for testing, and none was used more than once.

Extreme care was exercised in all handling of test fish. Transfers from the holding box and into the live boxes or test chambers were accomplished with a nylon dip net, and exposure out of the water was kept to a minimum. The adequacy of the handling techniques is evident in that: (1) in the 1963-64 studies, no mortalities ever occurred at Control Stations 1, 2, or 3, and 100% survival was recorded at least once at every station except Stations 6 and 10; and (2) in the 1965 studies, no mortalities were ever recorded at Control Station A, and 100% survival was obtained in 3 out of 20 tests at Station B.

The live boxes used in the 1963-64 studies were fiber glass cylinders, 24 inches long and 12 inches in diameter (Figure 8-4A). The ends were covered with 1/8-inch-mesh nylon netting to retain the test fish but permit free circulation of water through the box. A cedar block, bolted either to the inside or outside of the box, provided buoyancy to float the box at the surface as shown in Figure 8-4B.

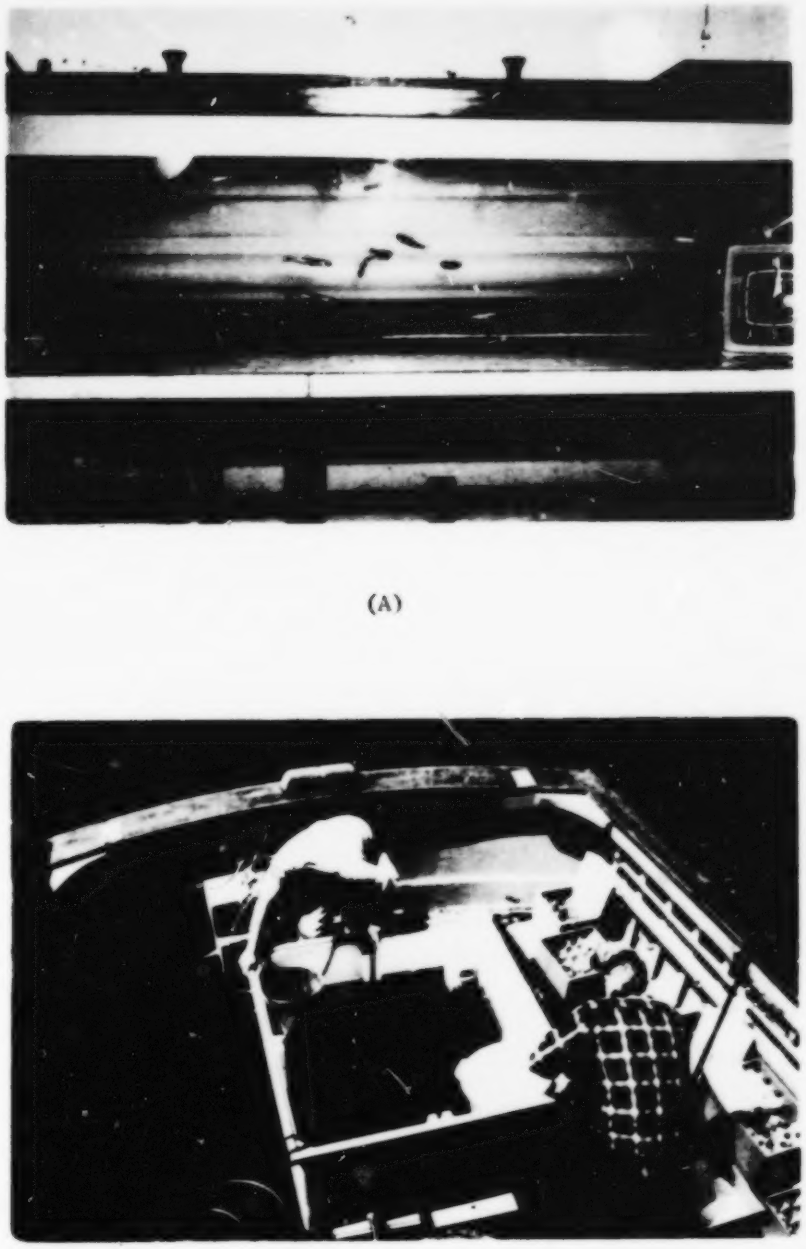
One of the two test chambers used in the 1965 studies was a clear lucite box, 48 inches long, 6 inches wide, and 10 inches deep (Figure 8-5A). Water depth was maintained at 7 inches. The



(A)

(B)

FIGURE 8-4. Live boxes used in in situ juvenile salmon bioassay studies: (A) typical live box and (B) live box as placed at a station for an exposure test.



(A)

(B)

FIGURE 8-5. Test chambers used in the 1965 bioassay studies in Bellingham Harbor: (A) lucite test chamber, and (B) standard live box (inside large wooden tank) test chamber.

transparent walls and the back-lighting of the chamber permitted both visual and photographic observations of test fish reactions and mortalities. The other test chamber (Figure 8-5B) consisted of a standard live box (Figure 8-4A) positioned vertically and half submerged in a wooden live tank (47 inches square, 12-inch water depth). The submerged end of the live box was covered with bobbinet to retain the test fish but permit water circulation. The exposed end was left open to facilitate observation of test fish.

In the 1963-64 studies, samples of near-surface water at each live box were collected with a Kemmerer sampler. In the 1965 studies, samples were siphoned directly from the test chambers. Sample analyses in 1965 were:

Temperature: with a mercury thermometer.

Salinity: with a Hytech, Model 6210 inductive salinometer.

DO: with a Beckman, Model 777, probe analyzer.

pH: with a Beckman, Model GS, meter.

SWL (10% solids): by the modified Pearl-Benson method (Barnes, *et al.*, 1963).

H_2S: by the Hach lead-acetate method.

NH_3-N: by the distillation method (A.P.H.A., 1962).

Temperature, DO, pH, and H_2S were analyzed on board ship immediately after collection. Sample analyses in the 1963-64 studies were the same except that NH_3-N was not determined; pH was determined with pH paper; and, in some cases, DO was determined by the Alsterberg modification of the Winkler method (A.P.H.A., 1962).

RESULTS

Migration. Townet data collected by FRI were evaluated by the Project, and the results are given in Figure 8-6. The values shown are sampling-area catch rates--the average catches of juvenile salmon (all species) per ten minutes of tow for all tows in each of the sampling areas depicted in Figure 8-1A. Also shown is the arbitrary division of Bellingham Bay into three sections. The average catches of juveniles per ten minutes of tow for all tows in each section are shown as boxed values. Note that the highest sampling-area catch rates and the highest section catch rate occur in the easternmost sector of the Bay. These data show that the eastern shoreline is a major migration path for young salmon. This is confirmed by other townet and beach-seine data collected by FRI which show that Chuckanut Bay and Post Point are major schooling areas (Tyler, 1964). Consequently, large numbers of Nooksack River and Squalicum Creek outmigrants must move in and through Bellingham Harbor in their seaward migration. This is verified by the relatively high tow-area catch rates of 4.6, 9.7, and 3.9 obtained in the Harbor.

Project beam-trawl results show average transect catch rates of 8.9, 4.3, and 6.5 juvenile salmon per ten minutes of tow along Transects 1, 2, and 3, respectively (Figure 8-1B). Note the high catch rate (8.9) along Transect 1 which cuts through Bellingham Harbor.

Occurrence of Juveniles in Bellingham Harbor. Results of the mobile-fishtrap studies are given in Figure 8-7. The values shown are average area-catches of juvenile salmon (all species) per 10 minutes of run. Note that juvenile salmon were captured in all areas. These

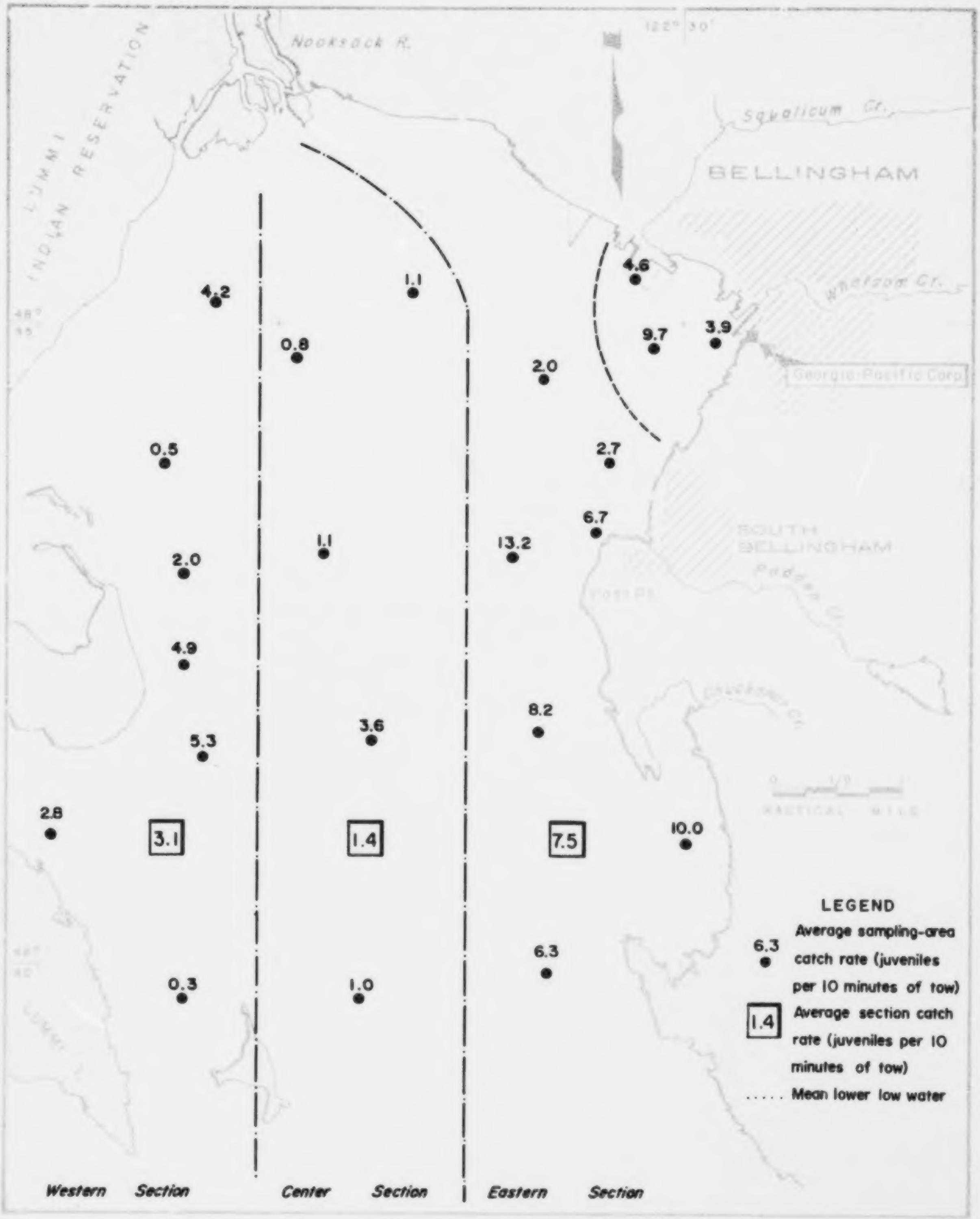

Nooksack R.
LUMMI INDIAN RESERVATION
122° 30'
Squalicum Cr.
BELLINGHAM
Whatcom Cr.
Georgia-Pacific Corp.
SOUTH BELLINGHAM
Post Pt.
Padden Cr.
Chuckanut Cr.
48° 45'
48° 40'
LUMMI I.
0 1/2 1
NAUTICAL MILE
4.2
1.1
4.6
0.8
9.7
3.9
2.0
0.5
2.7
6.7
1.1
13.2
2.0
4.9
8.2
3.6
5.3
2.8
3.1
1.4
7.5
10.0
6.3
0.3
1.0
LEGEND
6.3 ● Average sampling-area catch rate (juveniles per 10 minutes of tow)
1.4 Average section catch rate (juveniles per 10 minutes of tow)
..... Mean lower low water
Western Section
Center Section
Eastern Section

FIGURE 8-6. Average sampling-area and section catch rates of juvenile salmon in Bellingham Bay, from FRI townet sampling results.

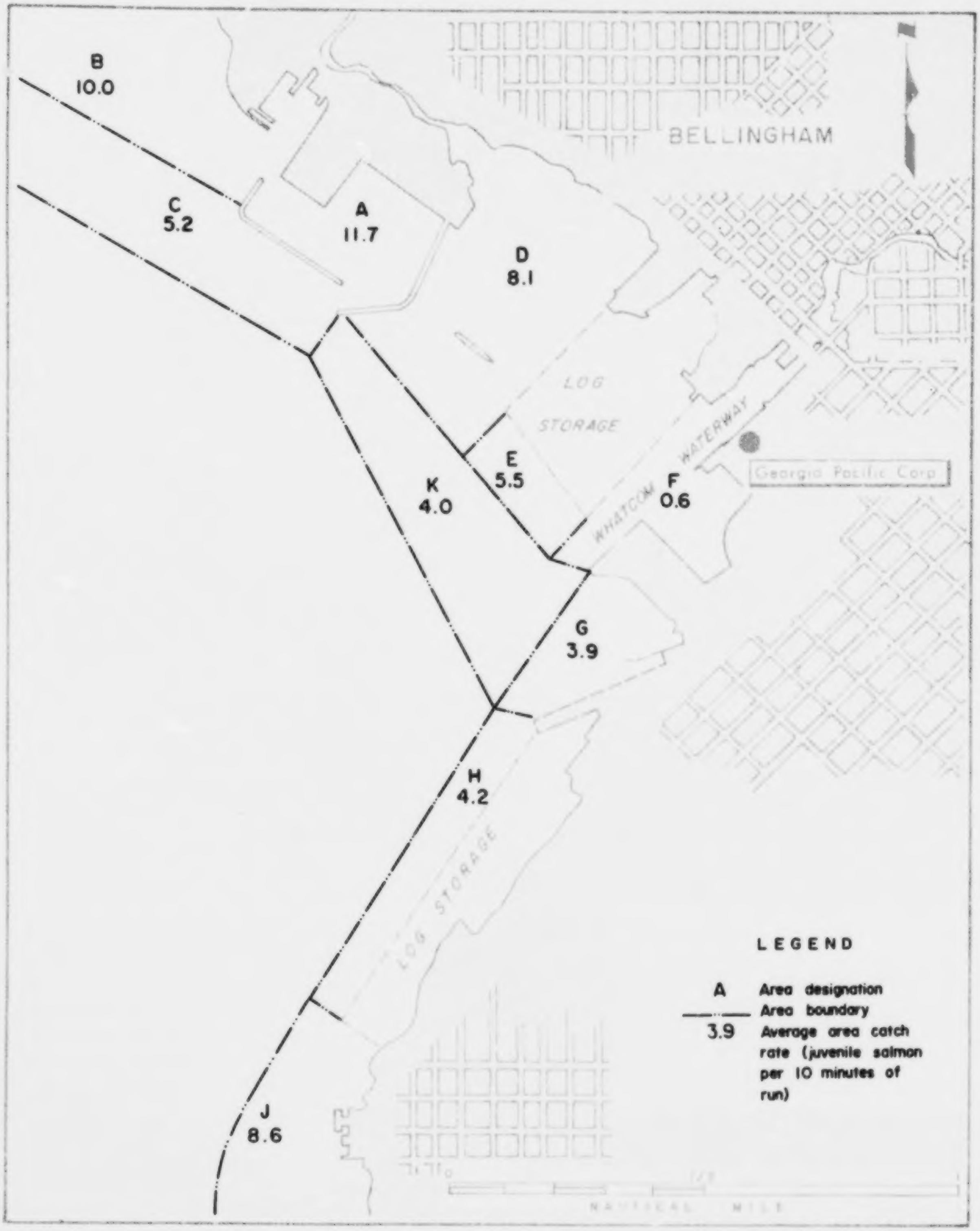

B
10.0
C
5.2
A
11.7
D
8.1
BELLINGHAM
LOG
STORAGE
E
5.5
K
4.0
WHATCOM WATERWAY
F
0.6
Georgia Pacific Corp
G
3.9
H
4.2
LOG STORAGE
J
8.6
LEGEND
A Area designation
Area boundary
3.9 Average area catch rate (juvenile salmon per 10 minutes of run)
0
1/2
NAUTICAL MILE

FIGURE 8-7. Average area catch rates of juvenile salmon in Bellingham Harbor, from Project fishtrap sampling results.

data demonstrate that outmigrants do move into Bellingham Harbor. Note, also, that fewer fish were captured in areas nearer the Georgia-Pacific waste discharge (into Whatcom Waterway) than in more distant areas. In Area F, no fish were captured on 8 out of 11 sampling days, hence an absence rate of 73%. Absence rates in the contiguous areas--D, E, G, and H--ranged from 18 to 25%, whereas absence rates in the remaining areas were either 0% or 8% (Areas A and C). Accordingly, these results evidence (1) some avoidance by young salmon of the more polluted areas and/or (2) some mortality and disappearance of juveniles which enter such areas (dead salmon sink).

Occurrence of Mortality. Percentage terminal mortalities observed at the end of 4-hour exposure in the bioassay tests conducted in the 1963-64 studies are tabulated in Table 8-1. Stations and data are arranged by area (see Figure 8-8) in accordance with the frequency and intensity of mortalities observed. The following facts are evident:

1. No kills ever occurred at control stations in Area A.
2. In Area B, kills occurred in 49% of the tests and these were usually high-percentage kills; *i.e.*, in 83% of the tests in which mortalities occurred, 20% or more of the test fish died, and in half of the tests in which mortalities occurred, all test fish died. Furthermore, 100% kills were observed one or more times at all stations in Area B except at Station 8.

TABLE 8-1. Percent mortalities of juvenile salmon after 4-hour exposure in Bellingham Bay, 1963-64 bio-assay studies.

	Area A			Area B									Area C				
	Station			Station									Station				
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
6/6/63					20				60	90							
6/7/63					80				70			70					
6/8/63	0	0		0	0		0			100					0	50	
6/10/63		0		100	100	100	100		0			100			90	0	
5/12/64			0	0	0		0				0	0			10		0
5/13/64			0	0	0		0		10		0	0			10		0
5/14/64			0	100	100		80		100		100	100			10		0
5/26/64			0	0	100		60	50	0		40	0	0	10			
5/27/64			0	0	100		100	50	10		0	10	10	10			
5/28/64			0	0	100		0	0	0		0	0	0	0			
5/29/64			0	0	0		10	0	0		0	0	0	0			

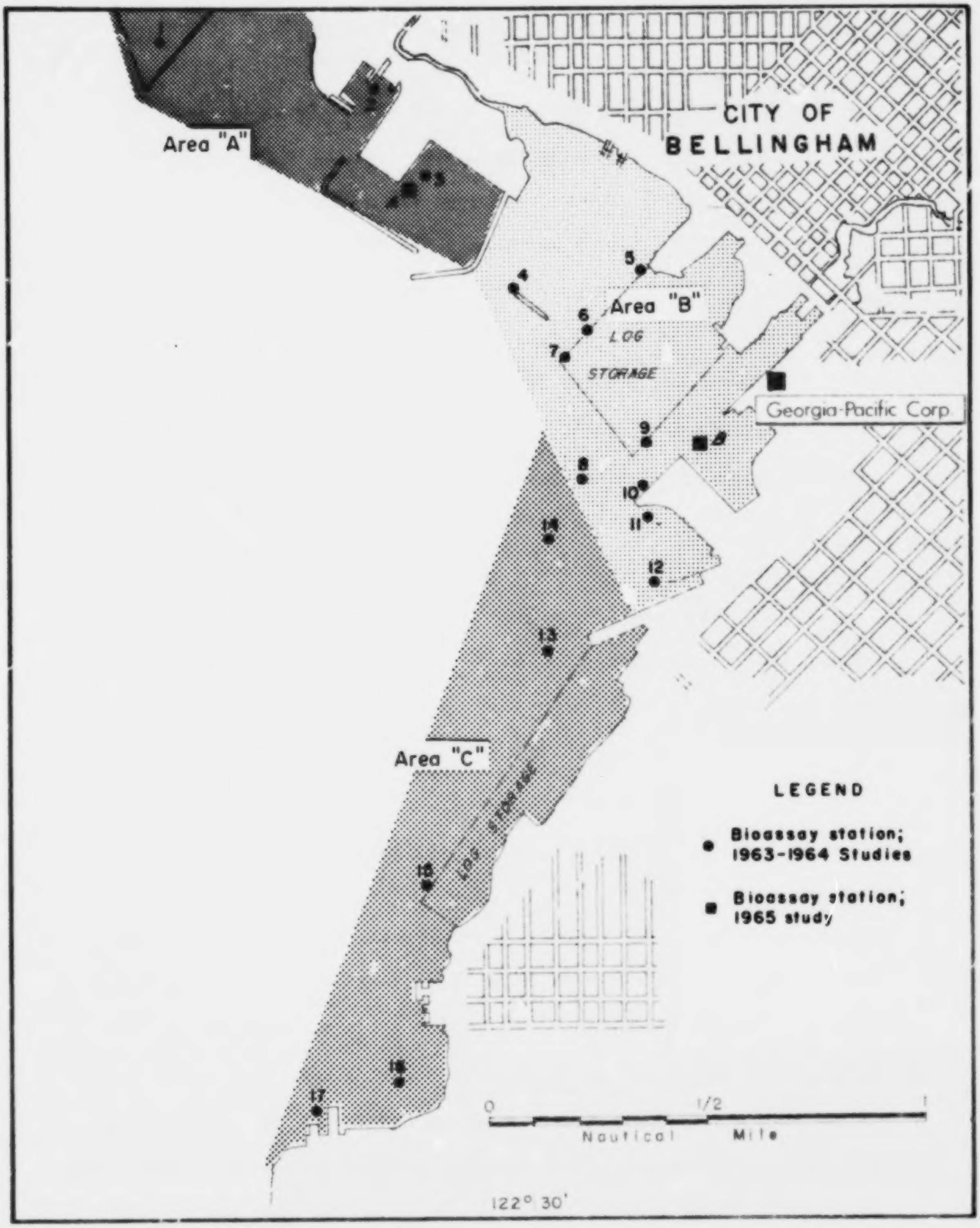

CITY OF BELLINGHAM
Area "A"
Area "B"
LOG STORAGE
Georgia-Pacific Corp
Area "C"
LOG STORAGE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
LEGEND
● Bioassay station; 1963-1964 Studies
■ Bioassay station; 1965 study
0
1/2
1
Nautical Mile
122° 30'

FIGURE 8-8. Juvenile salmon bioassay stations in Bellingham Bay; 1963-64 and 1965 studies.

3. In Area C, kills occurred in 45% of the tests but most of these were low-percentage kills; i.e., only two (25%) were kills of 20% or more, and none was a complete kill.

Results of the 24-hour exposure tests (1963-64 studies) are given in Table 8-2. Relationships similar to those above are evident; i.e., (1) no kills in Area A, (2) frequent high-percentage kills in Area B, and (3) frequent but usually low-percentage kills in Area C.

In addition to frequent high-percentage kills, mortalities in Area B often occurred after relatively short exposures. Of the fifteen cases of total mortality in 4-hour tests in this area, two of these complete kills actually occurred in 10 minutes or less, five occurred in 1 hour or less, and twelve occurred in 2 hours or less. Equally rapid kills also occurred in tests which terminated in mortalities of less than 100%. These results, then, together with those above, describe Area B as a zone where conditions are frequently acutely toxic to juvenile salmon.

Water Quality Associated with Mortalities. In the 1963-64 studies, it was observed that variations in wind and in tide stage caused considerable differences in water quality in the Harbor, and that these fluctuations in water quality, in turn, caused variations in observed bioassay mortalities. When 100% kills occurred in the 4-hour tests (Table 8-1), minimum observed DO's were always less than 2.4 mg/1 and maximum observed SWL's were always greater than 740 ppm. However, when no kills occurred (4-hour tests), minimum observed DO's were almost always (92% of the no-kill tests) greater than 2.4 mg/1 and maximum observed SWL's were usually (71% of the no-kill tests) less than 740 ppm.

TABLE 8-2. Percent mortalities of juvenile salmon at the termini of 24-hour exposure tests in Bellingham Bay, 1963-64 bioassay studies.

	Area A			Area B									Area C				
	Station			Station									Station				
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
6/6/63					100				100			100					
6/7/63					80				100			100					
6/8/63		0		0			0			100						80	
6/10/63				100	100	100	100					100					
5/12/64			0	0	0						100				10		0
5/13/64			0	100	100		100		100		100	100			10		0
5/14/64				100	100				100		100	100					
5/26/64			0	40	100		100		20		70	10	30	30			
5/27/64			0	10	100		100	100	60		50	10	90	10			
5/28/64			0	0	100		0	0	30		0	0	0	10			

Because of frequent water sampling, the 1965 bioassay study was better designed to reveal levels of water quality associated with mortality. Results of this study are summarized in Table 8-3. Note that these data are arranged in the three groupings: 100% kills at Station B, 0% kills at Station B, and 0% kills at Station A (see Figure 8-8 for station locations). The following features are described:

1. In the first grouping, 100% kills are associated with significantly high concentrations of SWL, low concentrations of DO, reduced pH's, and variable concentrations of NH_3-N--all of which evidence water quality degradation by mill wastes. In all cases, these observed values are below or approach the lethal limits (for each property) reported by others (Williams, et al, 1953; McKee and Wolfe, 1963).
2. In the second grouping, zero mortalities at Station B are associated with water quality values revealing some degradation by mill wastes but nevertheless showing lesser concentrations of SWL, higher DO concentrations, and higher pH's than noted in the first grouping.
3. In the third grouping, absence of mortalities at Control Station A are associated with quality values showing little influence of mill wastes; i.e., low SWL concentrations, near-saturation DO concentrations, normal pH's and low NH_3-N concentrations.

Other important features noted in Table 8-3 are the short exposure periods associated with many of the 100% kills. Of the

TABLE 8-3. Percent mortalities at termination of tests and summary of water quality data, 1965 bioassay study in Bellingham Harbor.

Date	Station	Mort. (%)	Exposure Time (hrs)	Exposure Time (mins)	SWL (ppm) Max.	SWL (ppm) Med.	DO (mg/1) Min.	DO (mg/1) Med.	pH Min.	pH Med.	NH_3-N (mg/1) Max.	NH_3-N (mg/1) Med.	Salinity (°/oo) Med.	Temp. (°C) Med.	Test Chamber
5/14	B	100	3	15	4470	3470	3.3	3.8	5.9	6.2	0.43	0.17	10.97	15.0	Live tank - Streeter
	B	100	2	42	7800	3810	3.3	4.4	5.9	6.3	0.49	0.08	12.80	15.2	Lucite tank - Streeter
	B	100	1	05	3560	3090	2.7	3.3	6.0	6.3	0.25	0.24	10.80	15.0	Satellite live box*
	B	100	0	35	3860	3655	2.8	3.1	6.2	6.2	0.25	0.24	11.53	16.1	Satellite live box*
	B	100	2	10	3720	3520	2.6	3.0	6.1	6.1	0.36	0.09	8.18	14.8	Satellite live box*
	B	100	3	35	3910	3350	2.0	4.8	6.1	6.2	0.08	- -	8.65	14.0	Satellite live box*
5/15	B	100	0	10	3760	3710	0.7	0.8	6.0	6.0	0.23	- -	8.93	- -	Live tank - Streeter
	B	100	0	08	1550	- -	- -	- -	- -	- -	- -	- -	- -	- -	Live tank - Streeter
	B	100	0	08	1550	- -	- -	- -	- -	- -	0.27	- -	- -	- -	Live tank - Streeter
	B	100	0	06	3270	- -	- -	- -	- -	- -	0.38	- -	- -	- -	Live tank - Streeter
	B	100	1	42	3920	2360	1.0	3.6	6.3	6.6	0.39	0.34	16.68	14.0	Lucite tank - Streeter
	B	100	0	40	5040	4060	2.2	2.8	5.3	5.7	0.46	0.40	10.99	14.7	Lucite tank - Streeter
6/2	B	100	1	45	8240	7410	4.3	5.9	4.2	4.4	1.11	1.02	3.58	19.0	Live tank - Streeter
	B	100	2	07	7870	2750	1.6	2.6	4.7	6.1	0.79	0.53	6.35	17.0	Lucite tank - Streeter
6/3	B	100	0	33	1790	1685	1.5	1.6	6.5	6.5	0.40	0.38	9.62	16.1	Lucite tank - Streeter
	B	100	0	15	1490	1470	1.4	1.6	6.4	6.5	0.34	0.29	9.30	16.5	Lucite tank - Streeter
	B	100	0	15	2080	1730	1.1	1.6	6.4	6.5	0.34	0.25	8.25	17.0	Live tank - Streeter
5/14	B	0	3	10	6820	2495	4.5	5.1	5.8	6.6	- -	- -	12.50	14.1	Satellite live box*
5/17	B	0	4	15	2380	1155	2.9	4.3	6.0	6.8	0.16	0.13	19.52	12.0	Live tank - Streeter
	B	0	4	00	2150	1670	4.5	5.8	6.1	6.4	0.34	0.28	10.50	11.8	Lucite tank - Streeter
5/14-15	A	0	29	25	123	84	8.0	8.6	7.3	7.5	0.08	0.025	6.69	13.2	Live box**
5/15	A	0	4	45	123	101	8.0	8.2	7.3	7.3	0.08	- -	8.34	12.9	Live box**
5/16-17	A	0	22	05	130	108	8.1	9.4	7.3	7.5	- -	- -	8.82	10.8	Lucite box - Streeter
5/17-19	A	0	46	45	123	60	7.6	7.8	7.6	7.9	- -	- -	24.96	12.2	Live box**
6/2-3	A	0	18	05	107	102	5.4	6.7	7.1	7.2	0.09	0.05	12.00	15.9	Lucite tank - Streeter

* Live boxes of the type shown in Figure 8-4 were placed as satellite boxes in the near vicinity of Station B and were operated in the same manner as those in the 1963-64 study except that water samples were more frequently collected.

** Control live box of the type shown in Figure 8-4 and operated in the same manner as those in the 1963-64 study.

seventeen tests in the first grouping, total kills occurred in 15 minutes or less in six of these tests and in 2 hours or less in twelve of these tests. In contrast, complete survival of test fish was obtained for as long as 4 hours and 15 minutes at Station B and for over 46 hours at Station A. Furthermore, observations of test fish behavior were that:

1. When water quality was poor or was rapidly deteriorating, test fish quickly became disoriented and engaged in erratic behavior and aimless, non-directional swimming.
2. Test fish showed no avoidance behavior.
3. In the moments preceding observed mortality, test fish invariably lost equilibrium and turned "belly up". Following this period, the fish made brief, spasmodic movements and then sank to the bottom. All 170 fish which died sank to and remained on the bottom of the test chambers.

DISCUSSION

Of considerable importance are the findings that test kills did not occur on all days at any one station and, on most test dates, that kills did not occur at all stations in Area B where toxic conditions most frequently occur. Hence, water quality favorable for normal survival of juvenile salmon often prevails in this area and does allow utilization of these waters by outmigrants of the Nooksack River and Squalicum Creek. This fact is substantiated by the fish-trap catches of young salmon throughout the Harbor (Figure 8-7). Once juvenile salmon enter Area B or Area C, however, they may swim into zones of polluted water or they may be entrapped in polluted waters which are moved throughout the Harbor by the actions of winds and tides. Several times, test fish, either in a live box or one of the test chambers, showed normal behavior before rapid degradation of water quality produced immediate morbidity and rapid kills. Increases in SWL concentrations at rates as high as 230 ppm per minute were observed, and rapid decreases in DO concentrations and pH values also were recorded. Certainly, the occurrence of 100% kills in 15 minutes or less in six tests of the 1965 study and 100% kills in 10 minutes or less in two tests in the 1963-64 studies show the rapidity with which acute toxic conditions can develop in Bellingham Harbor.

The numbers of wild juvenile salmon actually killed by lethal conditions in Bellingham Harbor are not known. In the first place, these young fish invariably sink when they die. Consequently, kills of juvenile salmon are not evidenced by floating dead fish as may be observed with other species. Secondly, in all cases wherein mortality occurred, death was preceded by loss of equilibrium and inability to avoid predators for periods as long as 20 minutes. Hence, some loss of wild fish can result from abnormally high predation. In view of these considerations and from the results heretofore presented, it is concluded that significant numbers of Nooksack River and Squalicum Creek juveniles are killed by polluted waters in Bellingham Harbor and, particularly, in that part of the Harbor designated as Area B.

Because test fish kills most frequently occurred in the waste-receiving waters of Area B, and because test kills were always associated with high SWL concentrations and low pH values (Table 8-3), wastes discharged by the Georgia-Pacific mill are definitely implicated as the cause of the test mortalities observed. The exact toxic components of these wastes and/or the other factors (DO, pH, etc.) actually responsible for these kills were not determined. However, studied evaluation of the 1965 water quality results leads to the conclusion that test mortalities were caused by the single or combined effect of (1) toxic mill wastes, (2) low dissolved oxygen concentrations, (3) low pH values, (4) high ammonia concentrations, and possibly, (5) other properties (e.g., CO_2 concentrations) not measured.

Results in Table 8-3 reveal that mortalities or distress behavior never occurred at Station A where SWL concentrations were always less than 150 ppm, DO concentrations were greater than 5 mg/l, pH values were greater than 7, and NH_3-N concentrations were less than 0.1 mg/l. Results from Station B indicate that, even at SWL concentrations in the range of 1,000 to 2,000 ppm, young salmon survived, providing that DO concentrations of about 5 mg/l, pH values of about 6.5, and ammonia concentrations of about 0.2 mg/l prevailed. However, when SWL exceeded 1,500 ppm in association with DO of less than 5 mg/l, pH of less than 6.5, and NH_3-N of greater than 0.2 mg/l (first grouping, Table 8-3), morbidity and mortality always occurred. Consequently, it is concluded that the following water quality criteria must be met at all times at all points in Bellingham Harbor if survival and well-being of migrating Nooksack River and Squalicum Creek juvenile salmon are to be assured:

SWL	less than 1,000 ppm
DO	greater than 5 mg/l
pH	greater than 6.5
NH_3-N	less than 0.2 mg/l

It is emphasized that these criteria are promulgated for the protection of fry and fingerling salmon only. The protection of other marine forms will require different criteria. Furthermore, these criteria are based on the present situation as affected by the types of wastes currently discharged by the Georgia-Pacific mill. If pulping or waste liquor recovery processes are significantly changed, for example, modification of or addition to these criteria may be required. For this reason, it is further recommended that water quality throughout Bellingham Harbor be adequate at all times to permit complete survival and normal behavior of juvenile salmon in 4-hour _in situ_ bioassay tests.

9. BOTTOM ORGANISMS

An important segment of the marine community of an estuary is the benthic fauna. This group of bottom-dwelling animals includes most of the crustaceans (e.g., crabs, shrimp, barnacles, amphipods, and isopods) and mollusks (e.g., clams and snails); many types of worms; and various other forms such as anemones, bryozoans, starfish, sea urchins, and sea cucumbers. The benthic fauna is an integral part in the food web of the marine community. Bottom fish feed heavily on benthos, and these fish and some of the larger benthic animals are food for larger carnivores. Also, the benthic fauna has a commercial and recreational importance. Certain benthic animals (crabs and shrimp) and many of the bottom-feeding fishes are harvested commercially, and some of these forms are taken by sportsmen.

Benthic animals populate all types of bottom, from soft muds to firm rock and gravel floors, but each bottom-type has its characteristic benthic community composed of those forms best adapted to the particular substratum. Deposits of sludge, however, often have a deleterious effect on the natural benthic community of an area. Such deposits bring about a physical change in the substratum, and many of the benthic types indigenous to the area are eliminated through burial and suffocation. Those benthic forms which do populate a sludge deposit are usually those species (e.g., certain types of worms) adapted to life in an unstable substratum rich in organic material. Quite often, these organisms are found in large numbers, but the community as a whole has

Preceding page blank

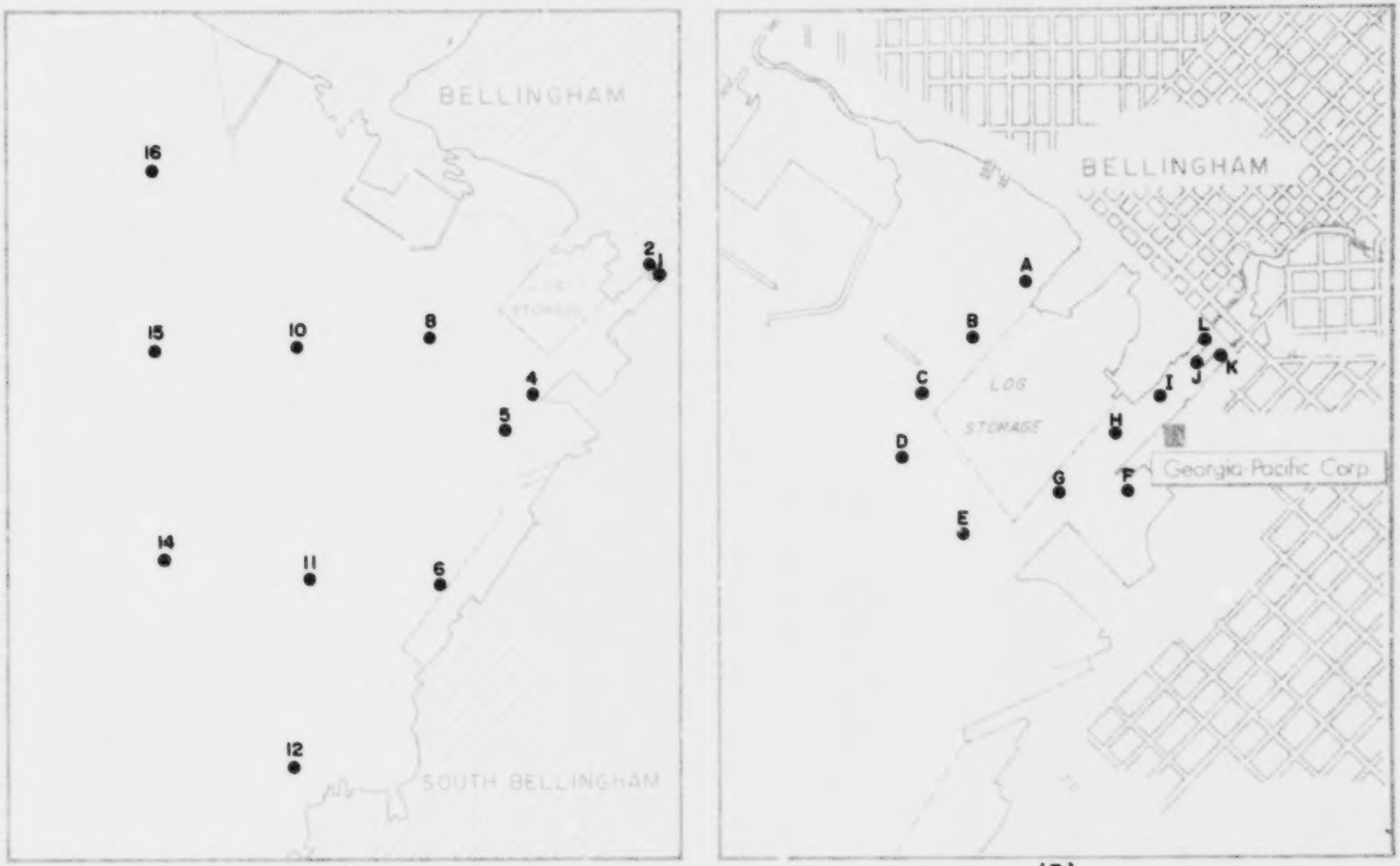
a very low diversity, thus, a deleterious effect. In some cases, the decomposition of organic material in a sludge deposit causes a substantial reduction or a depletion of dissolved oxygen on the bottom and produces such toxic gases as hydrogen sulfide and ammonia. These conditions are usually fatal to most animals, and they often eliminate all traces of benthic life.

STUDIES

Settled waste solids from the Georgia-Pacific pulp and board mill and paper mill have formed a sizable sludge deposit in Bellingham Harbor (see Section 7). This, in consideration of the above mentioned factors, led to the Project's conduct of two benthic studies in these waters. On August 11, 1964, a sediment sample was collected with a 0.25-cubic-foot van Veen dredge from each of the 16 stations shown in Figure 9-1A. These were analyzed for percent volatile solids of the sediment, and included benthos were identified and counted. On May 10, 1966, a sediment sample was collected with an 0.125 cubic foot Ekman dredge from each of the 12 stations shown in Figure 9-1B. These were analyzed and examined in the same manner as those of the first study.

METHODS

In both studies, the location and depth of each station were determined, and the volume, temperature, and gross appearance (color, odor, sedimentary composition, detritus inclusions) of each sample were noted. The sample was thoroughly mixed, and a portion was taken, frozen, and delivered to the laboratory for volatile solids analysis--


BELLINGHAM
16
15
10
8
2
1
4
5
14
11
6
12
SOUTH BELLINGHAM
BELLINGHAM
A
B
C
D
E
G
H
F
I
J
K
L
LOG
STORAGE
Georgia-Pacific Corp

(A) (B)

FIGURE 9-1. Benthic sampling stations in and about Bellingham Harbor (A) on August 11, 1964 and (B) on May 10, 1966.

the results of which have been summarily presented in Figure 7-14B. The remaining portion was placed in a glass jar containing a formalin preservative and a vital stain and was delivered to the laboratory for examination of the included benthos. In the laboratory, each sample was washed and screened. Benthic organisms were hand-picked from the screen and, under a microscope, were identified and enumerated. They were classified as to kind (or type); e.g., "worms" included segmented, unsegmented, round, and flat worms.

RESULTS

Results of both studies are summarized in Table 9-1. Note that seven kinds of benthos were found and that worms composed the dominant kind. Note, also, that greater numbers of organisms per sample were collected on May 10, 1966. Apparently, in the type of sediments sampled, the Ekman dredge used on this date was more efficient than the van Veen dredge previously employed.

Figure 9-2 shows plots of total number of organisms per sample vs. percent volatile solids of the sediment in the sample. Separate plots are given for the data from each of the studies because of the above-noted difference in sampling-gear efficiency. In both plots, these data fall into two groups: Group 1 wherein a wide range of total numbers is associated with volatile solids of 11% and less, and Group 2 wherein a much reduced range of total numbers accompany volatile solids of 15% and greater. Group 1 evidences natural variation in community size where organic content of the sediment is near natural levels. Group 2 represents conditions where accumulated sludge inhibits community size. In each plot, the hypothesis that the mean total

TABLE 9-1. Numbers and kinds of benthos, and percent volatile solids in sediment samples collected in Bellingham Harbor on August 11, 1964 and May 10, 1966

Station	Number of Organisms of Each Kind per Sample							Total Number of Organisms per Sample	Kinds per Sample	% Volatile Solids in the Sediment
	Worms	Amphipods	Isopods	Starfish	Crabs, Shrimp, Cumaceans	Clams, Snails	Bryozoa, Anemones			
					August 11, 1964					
1								0	0	31
2	2							2	1	28
4	4							4	1	15
5	73							73	1	8
6	16	3			1		1	21	4	10
8	77						6	83	2	8
10	26	2	4	2	1		4	39	6	7
11	8		3	2		1		14	4	8
12	27	4	1	4				36	4	8
14	13	4	1	1		2	3	24	6	8
15	24	1	4	1	1			31	5	8
16	120	2	1	2	1			126	5	5
					May 10, 1966					
A	55							55	1	21
B	1,094							1,094	1	8
C	9,128					15		9,143	2	11
D	2,415	63	43	21	95	42		2,679	6	9
E	2,891							2,891	1	9
F	984							984	1	30
G	58							58	1	18
H	36							36	1	20
I	12							12	1	32
J	7							7	1	28
K								0	0	37
L								0	0	28

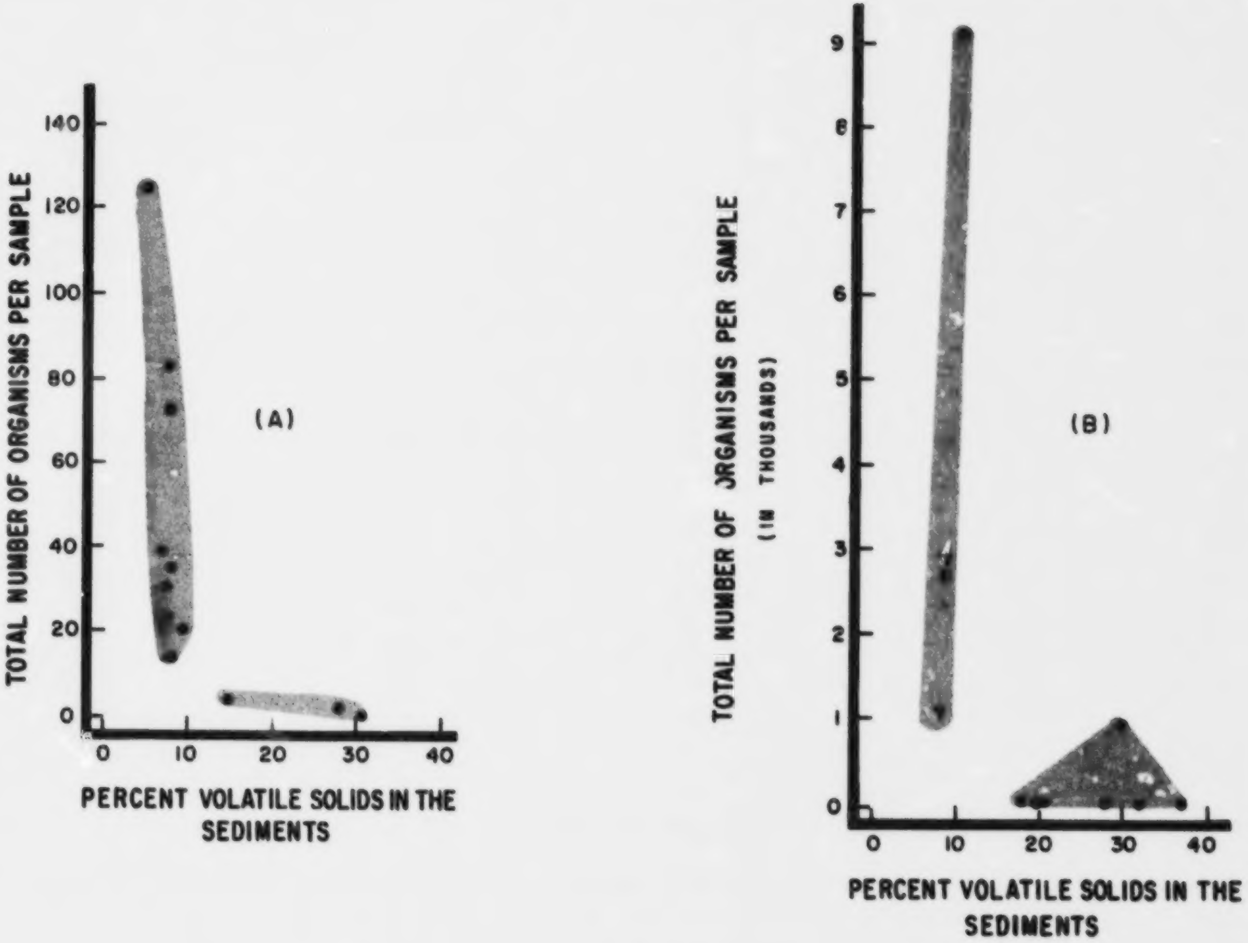


FIGURE 9-2. Total number of benthos per sample vs. percent volatile solids in the sediments of Bellingham Harbor, (A) on August 11, 1964, and (B) on May 10, 1966.

number of Group 1 differs from that of Group 2 is accepted at the 99% confidence level.

Figure 9-3 is a plot of kinds of organisms per sample vs. percent volatile solids of the sediment in the sample. Data from both studies are combined, as the difference in sampling-gear efficiency does not affect the kinds of benthos collected. This illustration clearly shows the trend of increasing community diversity (increasing kinds of benthos) with decreasing organic content of the sediments. This monotonic association is significant at the 99% confidence level.

Figure 9-4 delineates the areas occupied by Groups 1 and 2 (of Figure 9-2) and summarizes the differences in the community structure of these benthic groups. Area I is occupied by Group 1 and is affected by accumulated sludge which causes sediment volatile solids to exceed 15%. Area II is occupied by Group 2 but is little affected by sludge deposits; hence, sediment volatile solids are at or approach natural levels (7 to 8% for Bellingham Bay). Note, that on both study dates, the numbers and kinds of benthos in Area I are significantly exceeded by the numbers and kinds of benthos in Area II.

DISCUSSION

The above results clearly show that the thick sludge deposit in Whatcom Waterway and adjacent log storage area (see Figure 7-14A) adversely affect the benthic community of these waters Where sludge thickness is greatest, at the upper end of the Waterway (Stations 1, 2, K, and L; Table 9-1), no benthos are found. As sludge thickness and volatile solids decrease, increasing numbers of benthos are found, but these are of one kind, worms. Outside of the area of heavy sludge

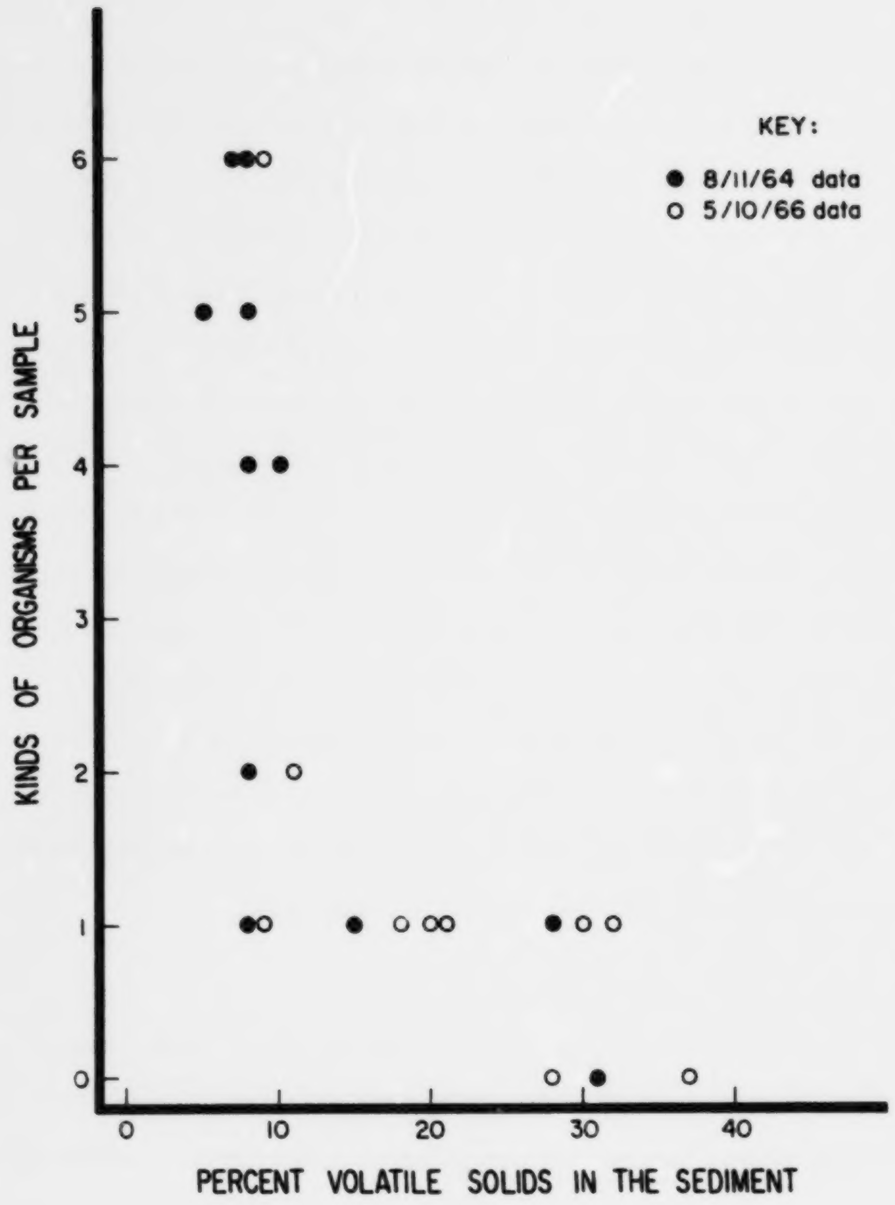
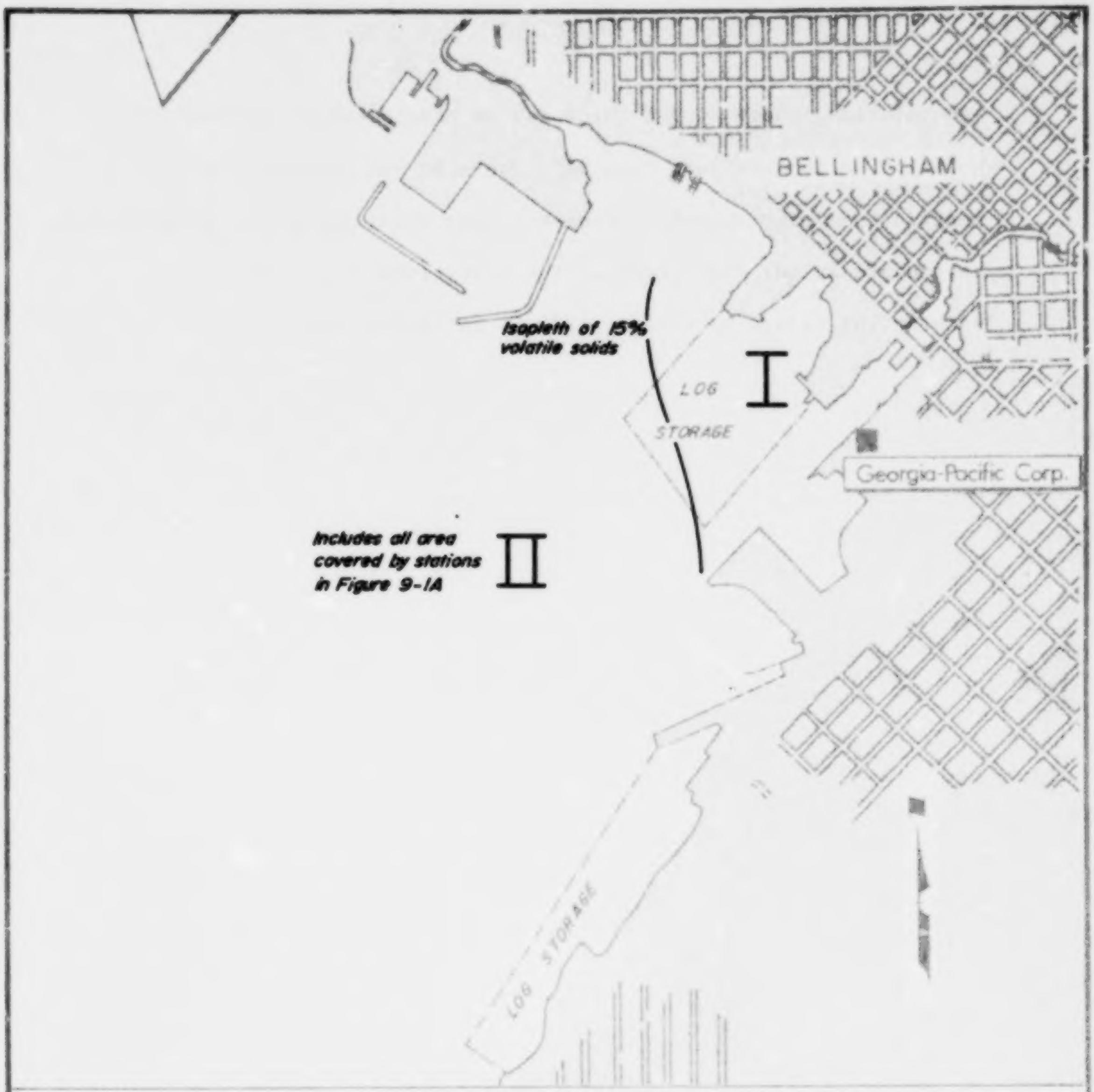


FIGURE 9-3. Kinds of benthos per sample vs. percent volatile solids in the sediments of Bellingham Harbor on August 11, 1964 and May 10, 1966.


BELLINGHAM
Isopleth of 15% volatile solids
LOG STORAGE
I
Georgia-Pacific Corp.
Includes all area covered by stations in Figure 9-1A
II
LOG STORAGE

			Number of Organisms/sample		Kinds/sample	
Date	Area	Group	Range	Median	Range	Median
8/11/64	I	1	0 - 4	2	0 - 1	1
	II	2	14 - 126	36	1 - 6	4
5/10/66	I	1	0 - 984	24	0 - 1	1
	II	2	1,094 - 9,143	2,785	1 - 6	2

FIGURE 9-4. Comparison of benthic populations in Areas I and II of Bellingham Harbor on August 11, 1964, and on May 10, 1966.

accumulation, where sludge thickness is undetectable, and sediment volatile solids are less than 15%, the size and diversity of the benthic community sharply increase. From these facts, it is concluded that waste solids discharged by the Georgia-Pacific mills cause substantial damage to benthic life in Bellingham Harbor.

10. OYSTERS

Historically, Bellingham, Samish, Padilla, and Fidalgo Bays have been oyster-producing areas. The native, or Olympia, oyster occurred naturally in these waters and was found in harvestable numbers by early settlers of the region. Commercial exploitation, however, gradually depleted these populations and today few Olympias can be found in the study area. This exploitation and the infrequent spawning and setting of the Olympia oyster because of unfavorable water temperatures are given as the chief causes of its disappearance (Steele, 1964).

Adult Pacific oysters were imported from Japan in 1919 for planting in Samish Bay. These adults died in transit, but the "spat" (young oysters attached to the adult shells) survived and grew after planting. This gave impetus to the commercial production of Pacific oysters which today is a well-established industry. Through 1964, the ten-year average annual production of Pacific oysters in North Puget Sound was over 58,000 gallons of oyster meats (Robison, Ward, and Palmen; 1965), although there has been a general decline in production since 1954. Production for 1964 was less than 49,000 gallons. The locations of commercial and potentially-commercial oyster-growing areas in the Bellingham-Anacortes study area are shown in Figure 10-1.

Although adult Pacific oysters grow and frequently spawn in the study area, complete larval development and spatfall (the attachment of young oysters to a substrate) occur infrequently because of unfavorable conditions. The last known significant spatfall occurred in 1958

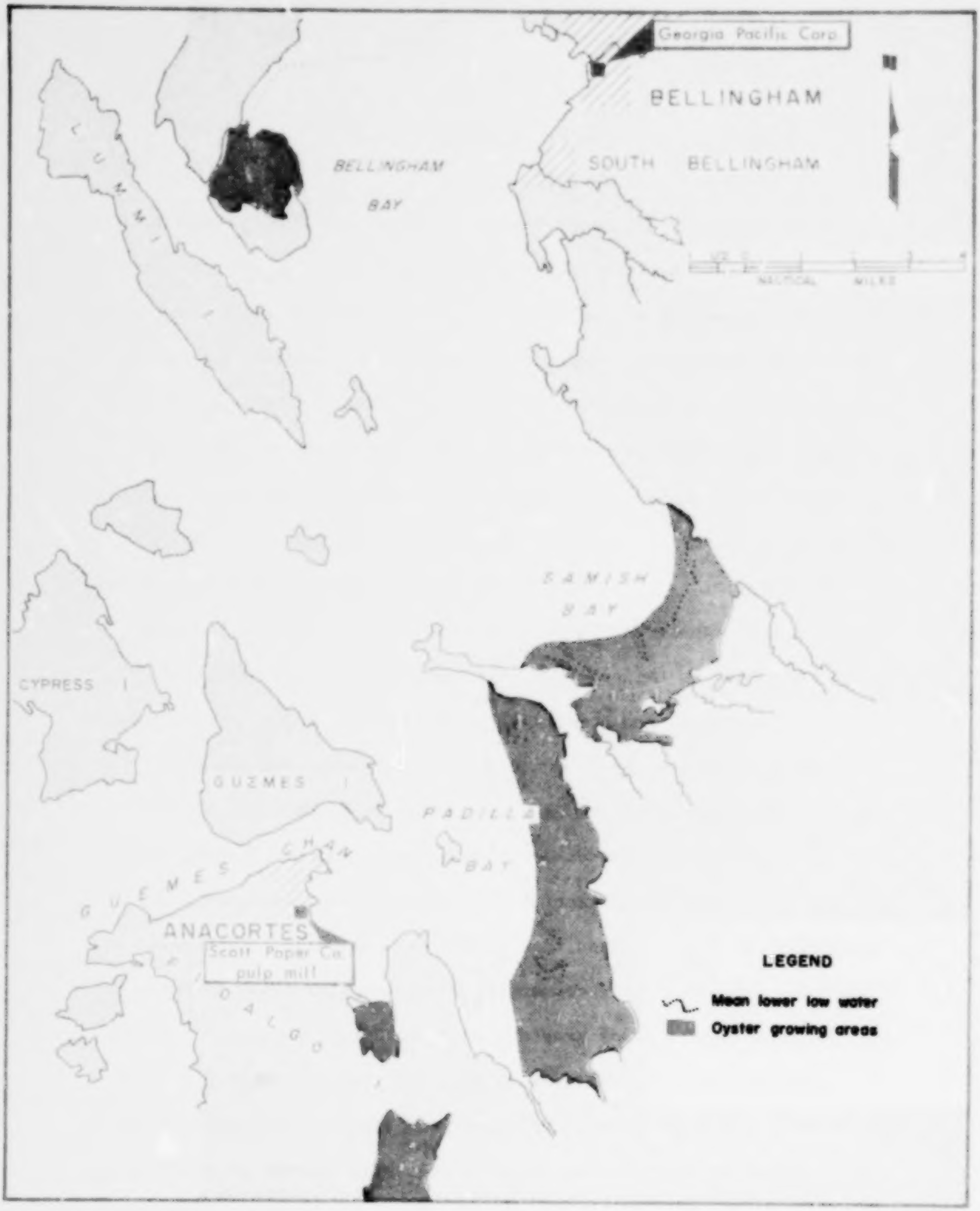

Georgia Pacific Corp
BELLINGHAM
SOUTH BELLINGHAM
BELLINGHAM BAY
LUMMI I
NAUTICAL MILES
SAMISH BAY
CYPRESS I
GUEMES I
PADILLA BAY
GUEMES CHAN
ANACORTES
Scott Paper Co. pulp mill
FIDALGO
LEGEND
Mean lower low water
Oyster growing areas

FIGURE 10-1. Commercial and potentially commercial oyster growing areas in the Bellingham-Anacortes area.

(Woelke, 1959); only limited sets of Pacific oysters and rock oysters (*Pododesmus macroschisma*) have been observed during this study. For this reason, the industry is based on growing marketable oysters from planted seed oysters (spat). Most seed oysters are imported from Japan, although limited supplies of domestic seed are produced in Dabob Bay, Washington, and Pendrell Sound, British Columbia.

A number of other edible bivalve shellfishes occur naturally in the Bellingham-Anacortes area, and these support a significant sport fishery. Among these are butter clams, native littleneck clams, Manila or Japanese littleneck clams, cockles, and the geoduc. These shellfishes, like oysters, are filter feeders and are sedentary or sessile forms.

Previous studies by other agencies have shown that SWL evokes comparable responses from larval, juvenile, and adult stages of several kinds of shellfish as well as other marine organisms with pelagic and/or sessile life stages. Examples of the kinds and life-stages of shellfish tested are:

Pacific oyster -- larvae, juveniles, and adults;
Olympia oyster -- larvae, juveniles, and adults;
American oyster -- larvae;
Hardshell clam -- larvae and juveniles;
Nester clam -- larvae; and
Bay mussel -- larvae.

Although two of these shellfish are not found in the study areas, the striking similarity of responses to SWL is strongly indicative of the effect of this waste on most, if not all, related species. In the absence of evidence to the contrary, it is not improbable that the observed effects of SWL on the indigenous shellfishes listed above are representative of the effects of SWL on the other resident species as well.

ADULT OYSTER RESPONSE STUDY

The adult oyster response study in the Bellingham-Anacortes area was conducted from April 1964 to July 1966 to determine the effects of pulp-mill wastes on the commercially important Pacific oyster and on other bivalve shellfishes. This study was a long-term, in-situ bioassay in which adult and juvenile Pacific oyster populations were maintained at raft stations. Initially, seven raft stations were located at various distances from the Georgia-Pacific mill (Figure 10-2). One raft, at Station C, together with all panels from Station D, were lost during the severe storms of December 1964, and another, Station D, was lost in late November 1965. Companion studies of the organisms that attached to the equipment during the study provided information on the effects of the wastes on other sessile forms.

Raft stations were chosen to permit the fullest expression of the effects of water quality on the oysters by avoiding the complicating effects of greatly varying bottom types and the mortalities caused by the natural enemies of oyster--starfish, oyster drills, crabs, etc. These and other advantages of the "hanging culture" method of oyster production are given by Cahn (1950).

METHODS

At each raft (Figure 10-3A), two discrete test populations of adult oysters were maintained. The Test #1 population initially

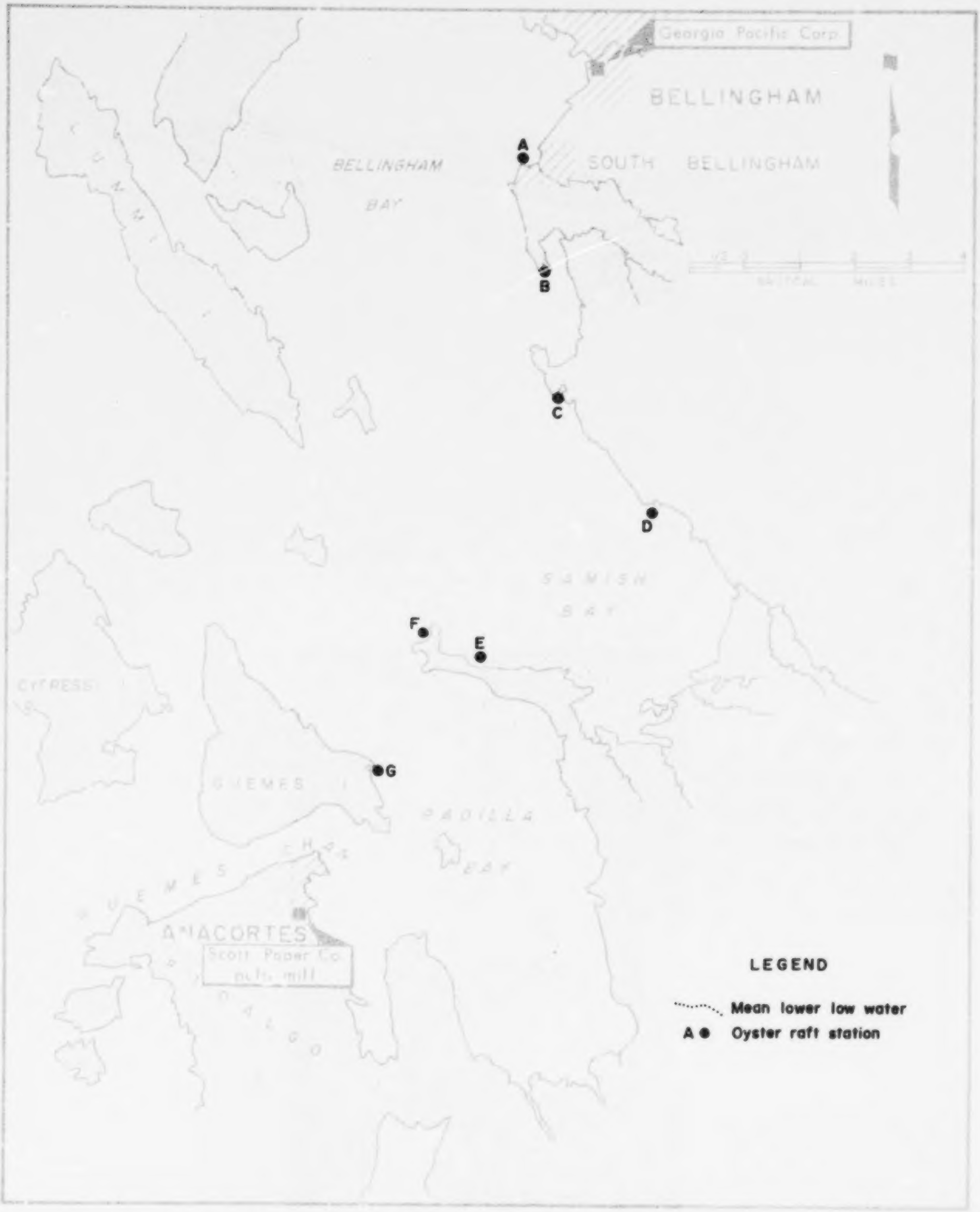
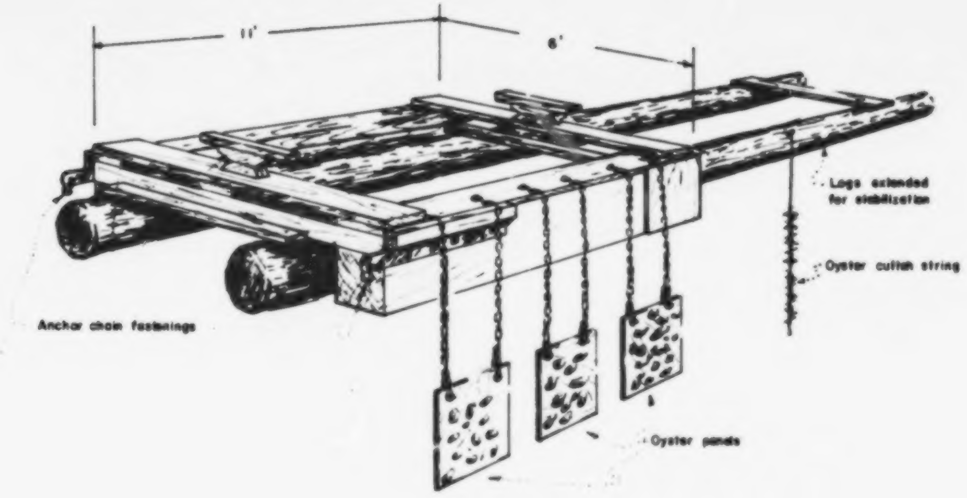

Georgia Pacific Corp.
BELLINGHAM
SOUTH BELLINGHAM
BELLINGHAM BAY
1/2 0 1 2 3 4
NAUTICAL MILES
A
B
C
D
E
F
G
SAMISH BAY
CYPRESS I.
GUEMES I.
PADILLA BAY
GUEMES CHANNEL
ANACORTES
Scott Paper Co. pulp mill
LEGEND
Mean lower low water
A ● Oyster raft station

FIGURE 10-2. Oyster raft stations in the Bellingham-Anacortes area.


11'
8'
Logs extended for stabilization
Oyster cultch string
Anchor chain fastenings
Oyster panels

(A) Oyster Raft

(B) Oyster Panel

Note mortality in bottom row, second from the right (upper shell has been removed).

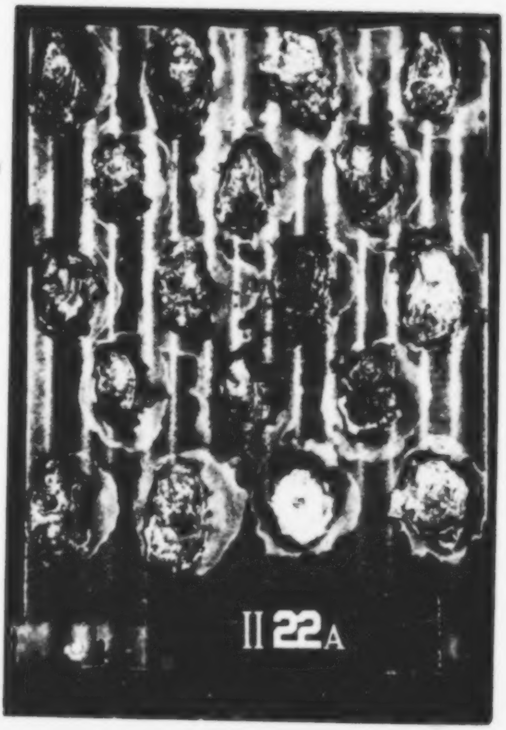


FIGURE 10-3. (A) Typical oyster raft; (B) Typical oyster panel.

consisted of about 175 each, of 1962 year-class and 1961 year-class oysters obtained from the Patterson Oyster Company, Totten Inlet, near Olympia, Washington. The Test #2 population originally consisted of about 200 1962 year-class oysters obtained from the Patterson Oyster Company, also. Both test populations were grown from Japanese seed and had not been exposed to SWL prior to use in the study.

The Test #1 population was placed at the rafts during April 1964 and the Test #2 population during May-June, 1965. The oysters of the two tests were cemented to both sides of fiber glass panels (Figure 10-3B) which were suspended from the rafts, as shown in Figure 10-3A. The uppermost row of oysters was about 2-1/2 feet below the surface. Both populations diminished in number during the study because of mortalities and other losses and the periodic sacrifices of test animals for the determination of "condition index" (a measure of fatness or market condition).

Populations of about 300 juvenile oysters (1964 year-class) also were maintained at each raft. These were placed in March 1965, and initially consisted of about 150 animals obtained from the Patterson Oyster Company and about 150 from the Blau Oyster Company, Samish Bay. The Patterson oysters were grown from Pendrell Sound, British Columbia, seed and had not been exposed to SWL. The Blau oysters were grown from Japanese seed and had been exposed to SWL in Samish Bay. The young oysters, attached to shell-cultch pieces, were suspended in the manner shown in Figures 10-3A and 10-4. The uppermost cultch piece was about one foot below the surface.

At monthly intervals, the oyster populations at each raft were examined for growth and mortality, and water samples were taken for

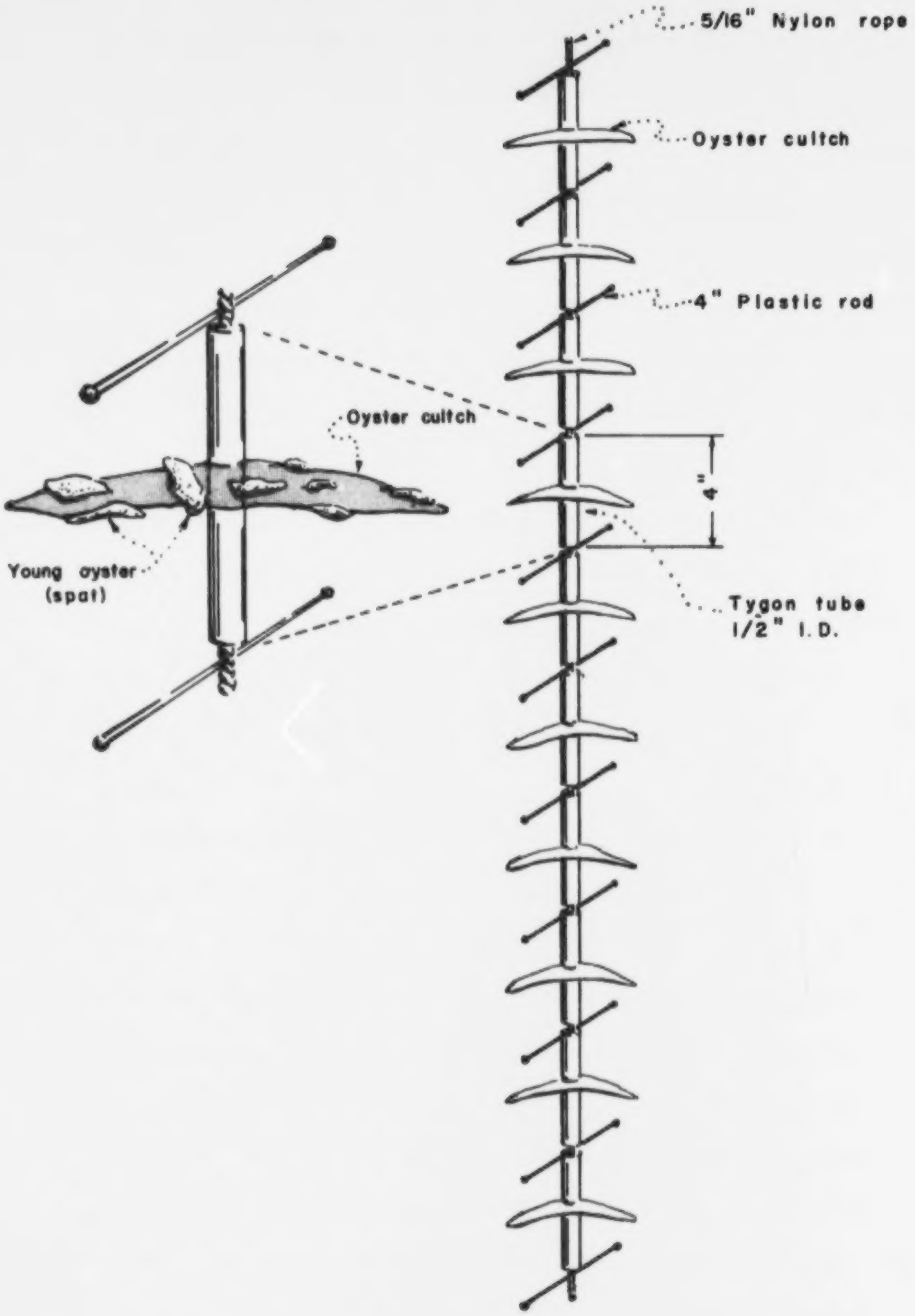

5/16" Nylon rope
Oyster cultch
4" Plastic rod
Oyster cultch
4"
Young oyster (spat)
Tygon tube 1/2" I.D.

FIGURE 10-4. Typical cultch string for the suspension of spat.

determination of salinity, SWL, DO, and temperature. Mortalities were evidenced by "gaping", the unnatural opening of the oyster's shell. The growth of spat was determined by volumetric displacement in water--an increase in volume from one sampling period to another representing the growth over that interval of time. The growth of the Test #2 oysters was determined by volumetric displacement also, but growth of Test #1 adults was obtained by photographing the oyster panels in a specially designed camera jig. In the latter method, the shell area of each oyster was measured with a planimeter on the photographs obtained (Figure 10-3B); the increase in area between inspections was considered a measure of growth. An analysis of the merits of various methods of measuring oyster growth is given by Quayle (1951), and the growth of Pacific oysters in Washington State waters is discussed by Woelke (1961a). Since the panels were numbered and the cultch pieces were identified by position on the strings, the maintenance of a continuous history of each individual adult animal or cultch piece was possible. The photos of the Test #1 panels also provided a record of the condition of these oysters.

At varying intervals, depending on the season, about 25 adult animals of the Test #2 population were sacrificed for the determination of condition index (C.I.) and growth. A limited number of C.I.'s were determined on Test #1 adults also. These C.I. analyses were done at the Washington Department of Fisheries Shellfish Laboratory by the method of Westley (1961). At the termination of the study, final C.I. determinations were made on all remaining Test #2 adult oysters and overall growth was determined.

Other organisms associated with the oyster-raft community were studied as well. Periphyton were collected on glass slides suspended in the water at and near each raft (this study is described in Section 14). In addition, periodic observations were made of the invertebrates attached to the oyster panels--*e.g.*, nudibranchs, flatworms, sea urchins, anemones, etc.--to determine the occurrence and abundance of these organisms in relation to distance from the waste source.

Considerable difficulty was experienced in maintaining the raft stations in the rough waters of Bellingham Bay during the winter months of the study. After the rafts had been put in place in late 1963 but before oyster populations were established, two of the rafts broke loose in stormy weather, were recovered, and returned to their respective stations. In early December 1964, the raft at Station D dragged anchor during a blow and, when found, had drifted to the vicinity of Station C. The Test #1 oyster panels were removed from the "D" raft and transferred to the Station C raft so that "D" raft could be towed back to station. Subsequently, the raft at Station C was lost in a severe storm with both populations. The raft at Station "D" was later lost during a storm in late November 1965. On one occasion, each, the rafts at Station F and Station G were moved out of position by storms. In summary, then, in decreasing order of overall exposure to adverse weather, the stations would be ranked C, D, F, G, E, B, and A.

RESULTS

The significance of the results of some of the various parts of the study is believed to have been obscured by the very marked differences in exposure of the raft stations to storms and heavy weather, as noted above. However, despite these obvious differences, all results were subjected to the same rigorous statistical analyses by Dr. G. J. Paulik, and only those results which show responses clearly overriding the differences that would be expected because of the physical differences between stations are considered to be indicative of the effects of SWL on juvenile and adult oysters.

Water Quality. A summary of water quality data for the two years of the adult oyster studies is given in Table 10-1. Note that sampling was done at the 3-foot level.

Mortality of Juvenile Oysters. A full discussion of analyses and results is given by Paulik in a report to the Project (1966b). Briefly, cumulative survival rates were computed using a modification of actuarial or life-table methods (Paulik, 1965c).

The strings of juvenile oysters used in this study were those used in the growth study. Mortality data were collected from April 29 to October 19, 1965, and the confounding effects of severe winter weather on survival were thus avoided.

Cumulative survival rates during the entire 5-1/2 month period for the animals attached to each cultch piece are given in Table 10-2. Missing entries are the result of losses of entire cultch pieces during the study for which survival rates cannot be estimated.

The mortality percentages estimated from the mathematical analysis of these data are:

A -- 15.4
B -- 6.2
D -- 7.9
F -- 4.8
G -- 4.0

TABLE 10-1. Water quality at raft stations, May 1964-June 1966 (3-foot depth).

Station	DO (ppm)			SWL (ppm)			Salinity (°/oo)		
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
A	6.6	7.6	0.0-12.8	331	148	20-2520	22.79	25.76	6.00-29.62
B	9.3	9.0	5.1-13.2	32	16	0- 281	27.06	28.04	9.90-30.29
C*	9.1	9.4	5.8-11.9	7	4	0- 56	28.34	28.53	22.57-30.32
D**	9.3	9.6	5.0-12.3	4	3	0- 14	28.14	28.56	14.21-30.10
E	8.6	8.8	5.6-12.2	5	3	0- 34	28.80	29.12	22.63-30.52
F	8.5	8.7	4.1-12.4	4	3	1- 17	28.94	29.14	23.21-30.46
G	8.4	8.3	5.3-11.1	3	3	0- 19	29.07	29.40	23.17-30.40

* Analyses to December 1964.
** Analyses through November 1965.

TABLE 10-2. Cumulative survival estimates for juvenile oysters for a 5-1/2-month period extending from the beginning of May to the middle of October 1965.

Source	Cultch piece	Stations A	B	D	F	G
Blau	1	.86	.89	1.00	.75	1.00
"	2	1.00	.89	-	.93	.89
"	3	1.00	1.00	1.00	1.00	1.00
"	4	.75	1.00	.71	1.00	.92
"	5	1.00	1.00	.87	.87	1.00
"	6	1.00	.71	-	-	1.00
"	7	1.00	-	.87	1.00	-
"	8	-	-	.94	1.00	1.00
"	9	.90	1.00	.89	-	1.00
"	10	.76	-	1.00	.90	-
Patterson	1	1.00	1.00	1.00	1.00	1.00
"	2	.90	1.00	.77	1.00	.91
"	3	1.00	.82	.92	1.00	1.00
"	4	.57	1.00	.85	1.00	1.00
"	5	.91	1.00	1.00	1.00	.92
"	6	.80	1.00	1.00	.94	1.00
"	7	.44	1.00	1.00	1.00	.71
"	8	1.00	.87	.87	1.00	.82
"	9	.50	.85	1.00	.94	.90
"	10	.56	.73	1.00	.92	1.00

These values and mean SWL levels (at the 3-foot depth) by station are shown in Figure 10-5.

When the data are subjected to non-orthogonal analyses of variance, the main conclusions of the study are:

1. The effect of station location on the mortality of juvenile oysters is significant at the 0.025 level (i.e., the results observed would occur by chance not more than 25 times in 1,000 trials). This significant location effect was due primarily to the sharp drop in average survival at Station A. The large mortality at this station was shown to be highly significant statistically. The environmental conditions at Station A clearly increased the mortalities suffered by the juvenile oysters held there.
2. Depth had little effect on mortality.
3. The overall estimated difference in mortality of about 3% between Blau and Patterson oysters is not significant. However, at Station A, the estimated mortality rate of 6.7% for Blau oysters is significantly lower than the 23.2% rate for Patterson oysters. The direction of this difference and the overall difference indicates that oysters from an outside source (South Sound) were more adversely affected by conditions closest to the mill discharge point than were the Blau oysters reared in Bellingham Bay. This probably reflects resistance developed by prior exposure (Blau oysters) rather than genetic differences because of seed source.

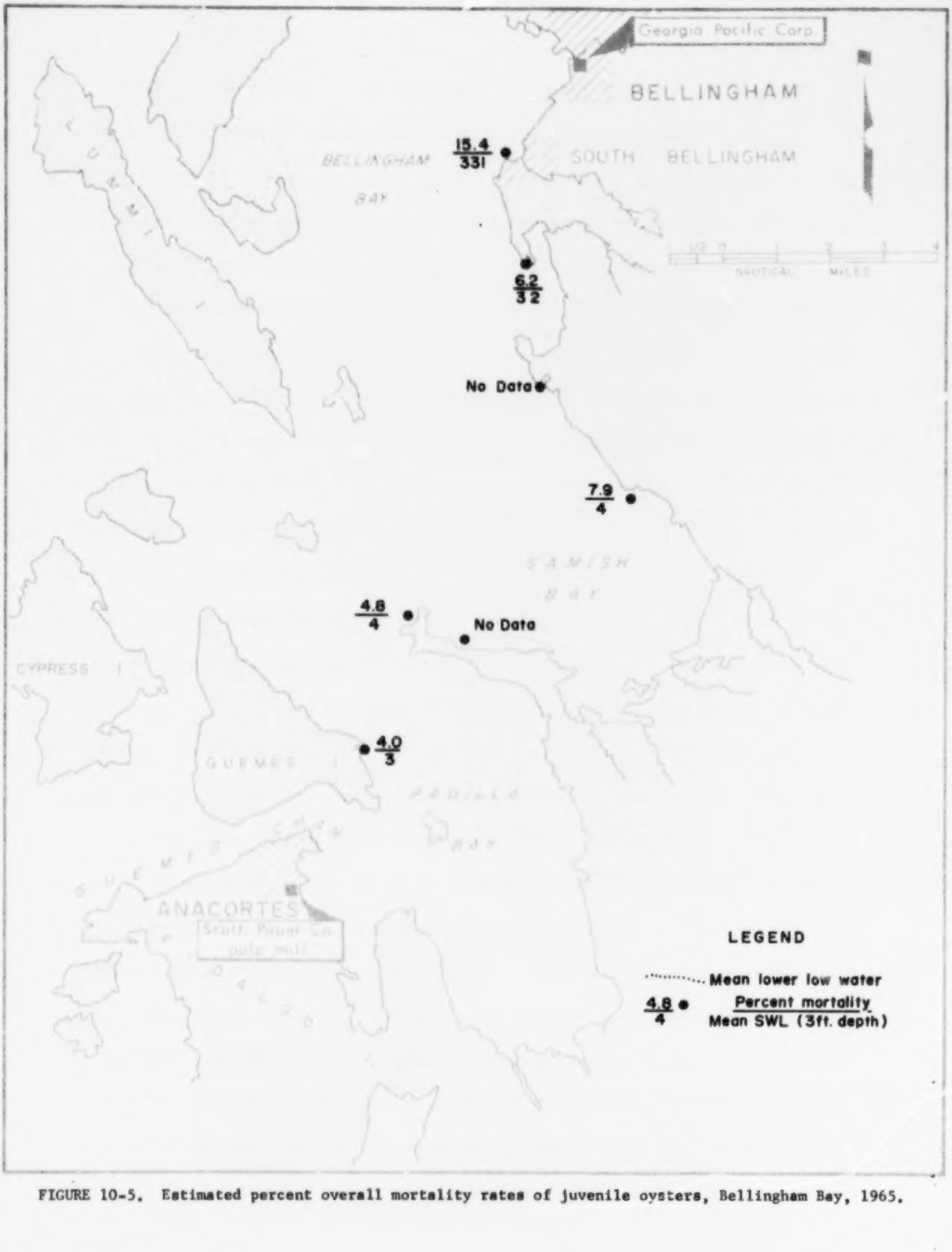

Georgia Pacific Corp.
BELLINGHAM
SOUTH BELLINGHAM
BELLINGHAM BAY
LUMMI I
15.4
331
6.2
32
No Data
7.9
4
SAMISH BAY
4.8
4
No Data
CYPRESS I
GUEMES I
4.0
3
PADILLA BAY
GUEMES CHAN
ANACORTES
Scott Paper Co. pulp mill
FIDALGO
1/2 0 1 2 3 4
NAUTICAL MILES
LEGEND
Mean lower low water
4.8
4
Percent mortality
Mean SWL (3ft. depth)

FIGURE 10-5. Estimated percent overall mortality rates of juvenile oysters, Bellingham Bay, 1965.

Mortality of Adult Oysters. Analyses of mortality of the Test #1 and the Test #2 adult oyster populations are given by Paulik in two reports to the Project (1965c and 1966c). In both years of these tests, the populations of experimental animals decreased very rapidly because of mortalities, drop-off losses, and periodic sacrifices for condition indices. Consequently, the effective sample sizes were rather rapidly reduced during the course of the two experiments, particularly during Test #2 when more frequent sacrifices for condition indices were made (e.g., nearly 60% of the original population at Station A were sacrificed during the experiment). These reductions in sample size and the severe winter weather (see page 110 of this section) are the apparent causes of a loss of experimental homogeneity during the latter half of each test such that the data obtained appear to be much less reliable and are subject to much greater variability than those obtained during the first part of the experiments.

Test No. 1 Mortality. An analysis given by Paulik (1965c) showed that there were no differences in survival rates between the 1962- and 1961-year class oysters in this study. The arithmetic means and standard deviations of the cumulative survival rates from May 8 to November 18 and to February 9 for the combined data from both year classes are given in Table 10-3. A complete detailed analysis of the data for each year class separately is given by Paulik (op.cit.). Following the November inspection the populations of oysters held at Stations C and D were lost in a severe storm. An analysis of the variability of the mortalities between panels at the same station showed that this intra-station variability increased significantly (at the 0.025 level) between the February 9 and June 10 inspection dates indicating that experimental control deteriorated markedly during the latter part of Test No. 1 in the winter and spring of 1965.

Inspection of the data presented in Table 10-3 reveals a trend of decreasing mortality with increasing distance from the mill. The observed straight line trend in mortality with distance from the mill was statistically significant (at the 0.025 level) for both the November and February sampling dates. These data are even more meaningful when the differences in exposure to weather conditions at the stations are considered.

TABLE 10-3. Mean percent combined mortality rates and standard deviations for Test #1 oysters.

	to November 1964		to February 1965	
Station	mean %	s.d.	mean %	s.d.
A	11.4	.064	15.9	.059
B	8.8	.090	10.7	.088
C	10.1	.077	--	--
D	8.3	.078	--	--
E	7.1	.053	10.1	.068
F	7.2	.050	9.0	.061
G	5.2	.036	8.1	.047

Test No. 2 Mortality. Since the primary objective of this test was the evaluation of the effect of mill wastes on the condition index of adult oysters, the effective sample sizes were rapidly diminished. Within six months, the populations at most stations had already been reduced to 40% or less of the initial sizes. The diminished sample sizes, and the loss of Station D in late November, makes questionable the validity of data obtained in the latter part of the test. These data are not included in the mortality data shown in Table 10-4.

TABLE 10-4. Cumulative percent mortality of Test #2 oysters at each station, May-November, 1965.

Month	Station					
	A	B	D	E	F	G
July	22.03	10.49	1.79	4.71	3.88	2.68
August	24.31	11.74	9.82	8.42	6.38	4.80
Sept.	28.84	15.35	16.19	10.55	9.81	8.23
October	30.16	17.34	18.34	14.21	14.49	14.53
Nov.	32.26	20.01	- -	17.68	26.02	23.48

When the average cumulative percent mortalities are computed on the basis of the successive monthly mortality percentages, the results to January 12, 1966 are:

A = 29.67%

B = 17.20%

E = 13.99%

F = 18.24%

G = 15.78%

On the basis of these data, the null hypothesis that station location has no effect on oyster mortality is rejected at the 0.01 level. It is obvious that the statistically significant differences in the station effect on mortality is due to the higher mortality rate at Station A.

Condition Index (C.I.) of Adult Oyster. A rigorous statistical analysis of the condition index as a valid biological assessment of the health or well-being of oysters and a complete evaluation of the Project's C.I. data are given in a report by G. J. Paulik to the Project (1966e).

The C.I. data for Test #1 (1964-65) are given in Table 10-5. The May sample was taken about a month after the oysters were distributed to permit recovery from handling stresses, if any. With the exception of Station C, the uniformity of C.I.'s between stations at that time is evident. The much larger value at Station C in May is a true outlier (0.05 level of significance) but, by August, the oysters at this station no longer differed from those at adjacent stations.

TABLE 10-5. Condition Indices of 1961 year-class oysters, Test #1.

	Station						
Date (1964)	A	B	C	D	E	F	G
May	11.6	12.8	16.0*	10.8	11.1	9.7	11.1
August	13.2	18.4	19.8	18.5	19.6	18.0	17.9

* A true outlier value.

The C.I.'s of the August sampling measure the influence of stations for the 3-months exposure. While the C.I. values for oysters at Stations B through G were not significantly different, the much lower C.I. at Station A, nearest the pulp mill, is a highly significant difference--the hypothesis that this lower value could have been an extreme value obtained by chance is rejected at the 0.01 level.

The C.I. data of Test #2 (1965-66) are given in Table 10-6. Since about three months elapsed between the placement of the oysters and the first sampling, all values measure the effect of station environment.

TABLE 10-6. Condition Indices of 1962 year-class oysters, Test #2.

Date	Station A	B	D	E	F	G
Aug. 1965	13.8	14.6	19.9	17.4	20.2	17.8
Oct. 1965	14.1	16.4	17.7	18.6	19.1	18.6
Nov. 1965	12.6	15.8	--	17.1	16.5	17.2
Jan. 1966	13.1	14.6	--	17.8	14.2	15.0
Apr. 1966	10.9	--	--	--	--	15.1
May 1966	10.4	15.3	--	15.9	16.2	12.3*

* This value is unusually low--over 1/2 of oysters showed development of sex products. If this datum is omitted from the analysis, the differences between stations become even more apparent.

Station C was lost during the Test #1 studies, and the series of samples at Station D is incomplete because of the loss of the raft in November 1965. The data for April 1966 are limited because of the few remaining test animals at the intermediate stations.

The condition indices of oysters at Station A were clearly much lower than any of the values at any of the other stations and reflect the consistently detrimental environment at Station A. This significant deterioration in oyster condition occurred in both Test #1 and Test #2 and also at different seasons within the same year.

The frequent sampling Test #2 permits the employment of a general linear hypothesis model to analyze these data. The estimated overall condition indices derived from the model for each station are:

A = 12.48
B = 15.09
D = 17.28
E = 17.11
F = 16.99
G = 16.00

Analyses of variance for these data show the station location effect is highly significant (0.01 level)--obviously because of the much lower value at Station A.

Growth of Juvenile Oysters. Descriptions of the statistical analyses used and a discussion of results are given by Paulik in a report to the Project (1966d).

The strings of juvenile oysters from both sources (*i.e.*, Patterson Oyster Co. and Blau Oyster Co.) were placed at the rafts in March 1965, and initial volumetric measurements were made in April 1965. The final growth measurements were made in February 1966 after about a 10-month period of exposure. During the study, one of the two strings at Station E was lost, and the entire Test #2 population at Station D was lost with the raft.

The volumetric measure of growth employed in this study overestimated the amount of growth when there were losses between the initial and the final measurements taken on a population of juveniles attached to a single cultch shell. Since it was shown in the mortality section of the report that juvenile oyster mortalities differed significantly between stations, the amount of bias in the growth measurement likewise differed from station to station. For this reason the growth data presented in Table 10-7, below, do not provide a valid indication of the effect of the environment on juvenile oyster growth.

TABLE 10-7. Observed and estimated average volume gain (in ml.) per oyster by source and station.

	Station							
	A		B		F		G	
Source	O*	E*	O	E	O	E	O	E
Blau	22.53	22.53	35.86	35.86	30.05	30.05	28.07	28.07
Patterson	27.51	27.51	29.29	29.29	18.84	18.84	22.89	22.89

* O--observed; E--estimated from mathematical model.

The average gains in volume by station estimated from the mathematical analysis of these data are: Station A--25.23; Station B--32.57; Station F--24.45; and Station G--25.47. The difference in volume gains between stations is significant at the 0.05 levels; but, because of the differences in mortalities, it is not possible to ascribe this significant difference in growth to the effect of environmental conditions on juvenile oysters.

Growth of Adult Oysters. Descriptions of the statistical analyses used and a discussion of results are given by Paulik in a report to the Project (1967).

The sensitivity of the Test #1 and Test #2 growth studies was affected by changes in numbers of oysters from station to station resulting from mortalities, drop-off losses, and periodic sacrifices of test animals for condition indices. Individual measurements were affected by shell chipping that occurred while the shells were being cleaned of attached organisms for photographing or for volumetric measurement. While overall differences in growth between stations were observed in both years, i.e., in Tests #1 and #2, because of the intra-station variability in growth and the inter-station variations in sample sizes, consistently significant differences in growth were not demonstrated by a preliminary analysis of these data.

Biota Associated with Oyster Panels. During these oyster studies, observations of animals attaching to or living on the panels were made routinely. Although time did not permit critical counts or exhaustive analyses of species, the absence or occurrence and relative abundance of various organisms was noted. Since the panels were cleaned during each sampling visit, either to photograph the oysters (Test #1) or prevent excessive accumulations of encrusting organisms, such as barnacles (Test #2), our observations reflect the success or failure of a significant species to repopulate within the inter-sampling period of about 30 days.

While there were annual differences in the abundance of certain species (e.g., the barnacle set was very heavy in the warmer months of 1964 and 1965 but was very light through July 1966), a general pattern of distribution related to distance from the pulp mill was obvious. Except for an unusual period between August 1965 and May 1966, discussed below, the distribution of species was as follows:

1. Not seen north of Station D, but common at all other stations--
    - bryozoa
    - chitins
    - limpets
    - nudibranchs (apparently quite sensitive)
    - pectens
    - polychaetes:
        - sirpulids
        - sabellids
        - nereis
    - goose barnacles
    - green shrimp

sea cucumbers

anemones

sea urchins

tunicates

ascidians

cling fish (rare)

blennies, 3 species

2. Rare or occasional at Station B, absent at Station A, but common to abundant at all other stations--

obelia-like hydroid

scale-bearing polychaetes

amphipods

isopods

skeleton shrimp

3. Abundant at all stations--

barnacles

mussels

The exceptional period noted above began about the middle of July 1965 and ended in late May 1966. During this period, a marked improvement in water quality at Station A was seen, and the assemblage of somewhat sensitive forms (category 2) began to appear. By October 1965, a few of the sensitive forms (category 1) were present, although none of them was as abundant as elsewhere. During this period, the mean SWL dropped to 168 ppm (overall mean--331 ppm) and other water-quality parameters likewise improved. By July 1966, however, water quality had deteriorated to former levels, and only barnacles and mussels persisted.

DISCUSSION

The results of this study and the one with larvae, following, demonstrate a marked difference in susceptibility to SWL with difference in age. The larvae are the most sensitive (see Section 11), followed by the juveniles and adults in order. Acute or immediate effects of SWL are shown by the larvae, whereas the chronic or long-term effects are shown in these studies with juveniles and adults.

The trend toward reduced mortalities of all of the age groups with increased distance from the waste source is evident in all of the tests, particularly in the juvenile and Test #1 adult studies in which population sizes were not rapidly reduced. A similar but less marked trend toward better condition of oysters at stations further from the waste is likewise evident. In every test, the effects of consistently adverse environmental conditions at Station A were shown to be highly significant. These findings are supported by the occurrence and abundance of other organisms associated with the oyster panels.

These tests demonstrate that water quality at points closer to the waste source than Station D is markedly detrimental to adult and juvenile oysters in one year or less. Therefore, mean SWL levels of about 10 ppm, with maximums of about 50 ppm, are shown to be harmful (see Table 10-1).

11. OYSTER LARVAE

Virtually every marine animal is planktonic at some phase of its life cycle. For many of the finfishes and shellfishes, this planktonic phase occurs during early development, usually during the egg or larval stage, or both. Later these forms develop into nektonic or benthic animals and no longer encounter the special problems of planktonic existence.

During its planktonic phase, the animal lives in the open water as a passively-drifting or weakly-swimming organism. Because of its feeble mobility, it is subjected to all prevailing environmental conditions and is unable to avoid those conditions that are injurious. At the same time, the animal usually is quite sensitive to its environment because it lacks many of the protective mechanisms of later development. Therefore, being sensitive to but a captive of its environment, the animal during its planktonic phase is often adversely affected by degrees and kinds of pollution which may be tolerated in its juvenile and adult stages. The result can be the decline or disappearance of the species.

Planktonic early-life stages of a variety of marine animals are found in the Bellingham and Anacortes area. Among these are the larvae of shellfishes--oysters, clams, crabs, etc. These forms are very sensitive to many pollutants, including pulp mill wastes, and, for the most part, are more susceptible to injury by such substances than are the juveniles and adults of the species (see Section 10).

At the same time, they live and develop in the near-surface waters wherein occur the highest concentrations of pulping wastes discharged by the Georgia-Pacific mill at Bellingham (see Figures 7-5, 7-6, and 7-7) and by the Scott mill at Anacortes (see Figure 19-4). Because of this portended damage to the valuable shellfish populations in the Bellingham-Anacortes area, the Project conducted two Pacific oyster-larva bioassay investigations--a field-sample oyster-larva response study and a waste-sample oyster-larva response study.

STUDIES

The field-sample study was initiated in May 1963 and terminated in August 1965. Surface samples of water (field samples) were collected at monthly intervals from the stations shown in Figure 11-1. Extra sets of samples from some of these stations also were collected on July 6, 1964, and on November 16 and 25, 1964, to evaluate water quality changes occurring during mill closure periods. Samples were air transported to the Washington State Department of Fisheries Shellfish Laboratory where they were bioassayed with Pacific oyster larvae. All bioassays and associated laboratory analyses were performed or supervised by Charles E. Woelke of the Laboratory's staff.

The waste-sample oyster-larva response study was similar to the above investigation. Twenty-four-hour composite samples of in-plant wastes were collected (1) from five sewers at the Georgia-Pacific pulp and board mill on July 14, 1964; (2) from the outfall sewer (total mill waste load) of the Scott mill at Anacortes on August 4, 1964; and

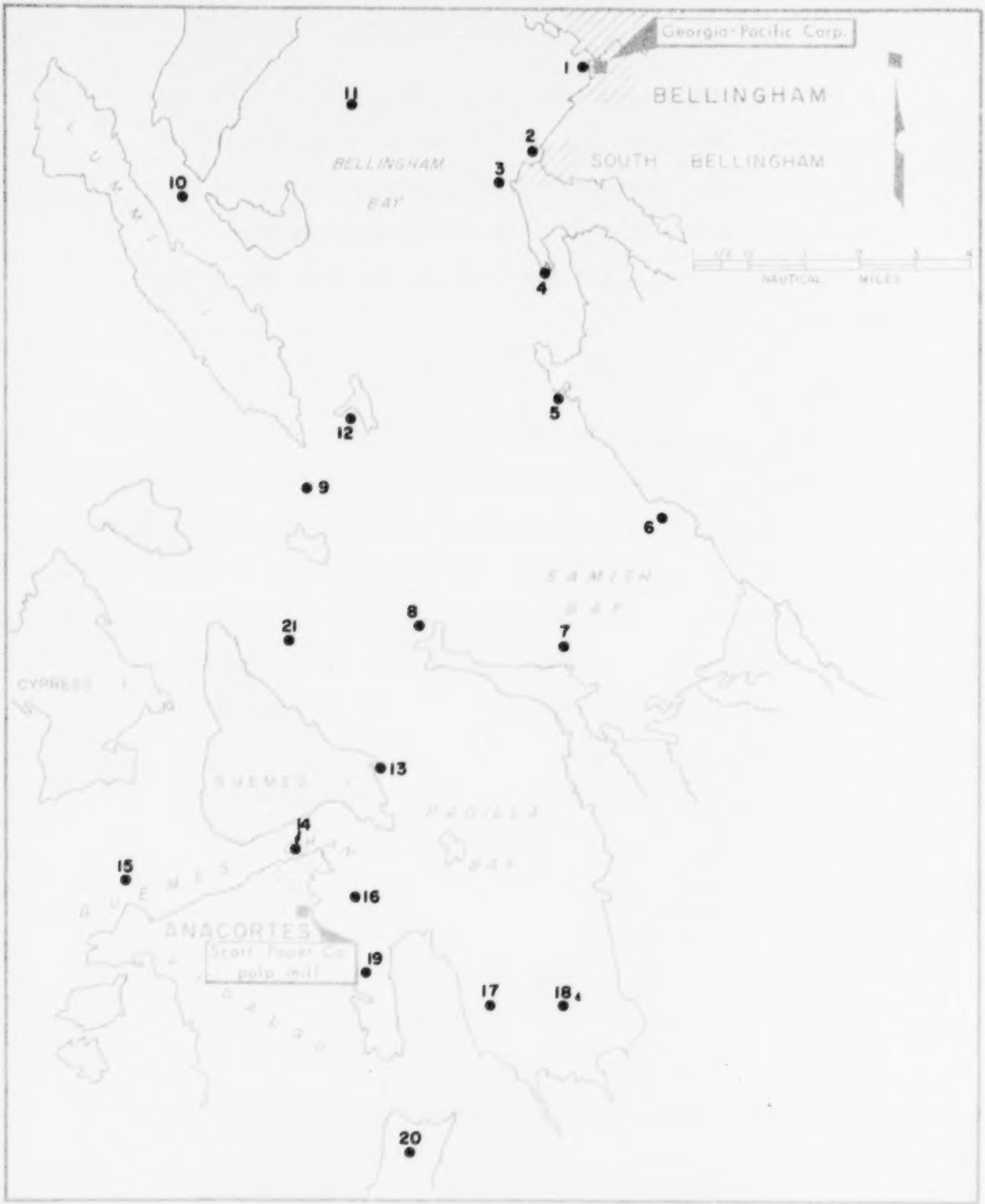

Georgia-Pacific Corp.
BELLINGHAM
SOUTH BELLINGHAM
BELLINGHAM BAY
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
1 1/2 0 1 2 3 4
NAUTICAL MILES
SAMISH BAY
CYPRESS I.
GUEMES I.
PADILLA BAY
GUEMES CHAN.
ANACORTES
Scott Paper Co. pulp mill

FIGURE 11-1. Water sampling stations, field-sample oyster-larva response study.

(3) from the outfall sewer (total mill waste load) of the Georgia-Pacific paper mill on March 3, 1965. Composited effluent samples also were collected from the Shell and Texaco oil refineries at Anacortes on January 19, 1965. All samples were bioassayed with Pacific oyster larvae in the same manner as the field samples from the above study.

METHODS

Field-Sample Study. The flow diagram, Figure 11-2, shows the basic feature of the field-sample response study. The series of boxes to the left illustrates the procedures used to obtain fertilized eggs; the series to the right deals with the collection of field samples and the initial analyses for chlorophyll, salinity, and SWL; and the lower center series shows the steps in the bioassay test, the measurements of responses, and the terminal chemical analyses. These procedures are as follows:

(left) 1. Conditioned female oysters were induced to spawn by raising the water temperature and introducing sperm shortly before field samples were to arrive at the laboratory.

2. A number of the resulting zygotes (fertilized eggs) were added to the replicate cultures of all field and control samples.

(right) 1. A four-liter field sample was collected at each station by seaplane and transported to the laboratory within three hours. Three

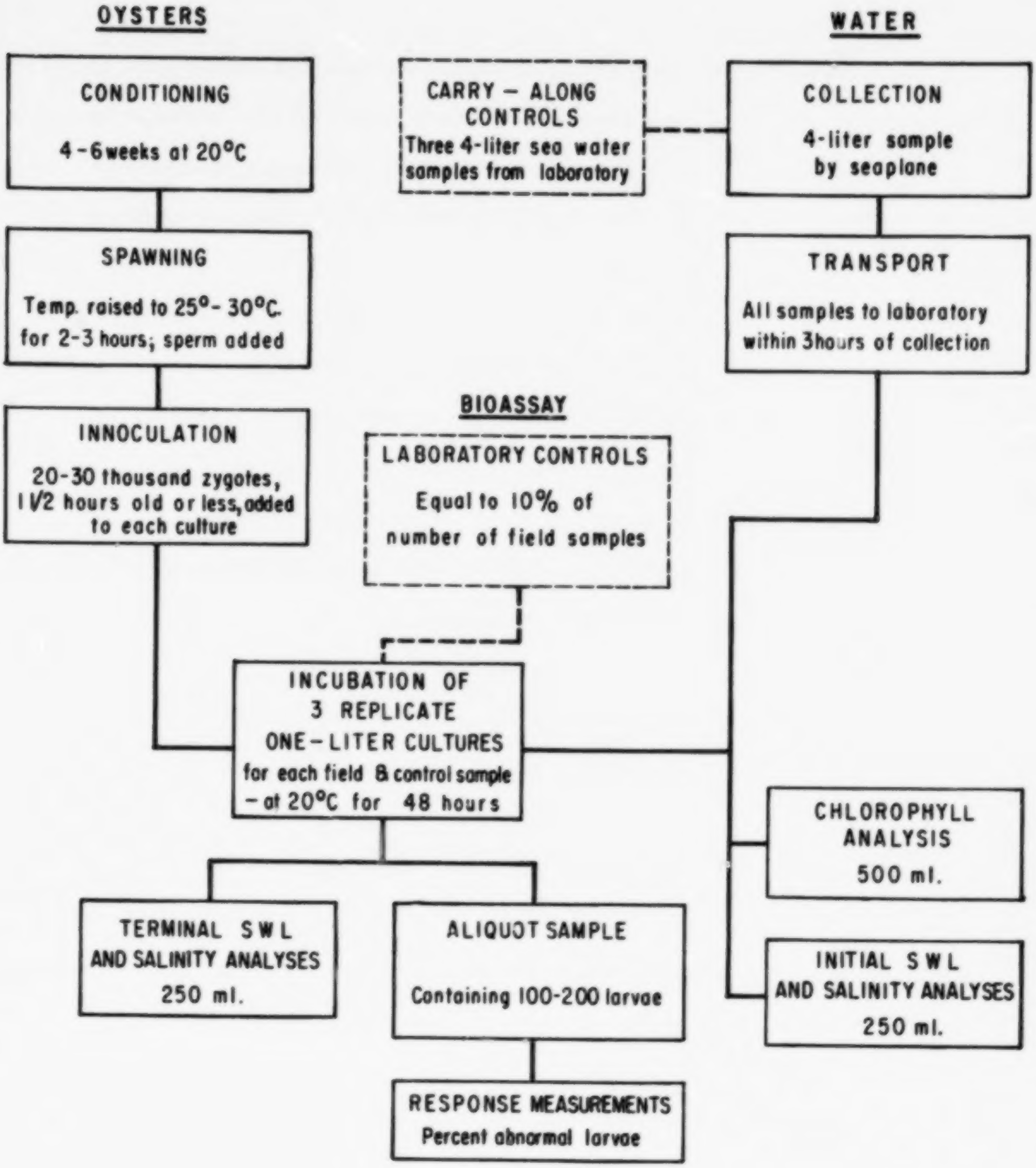

OYSTERS
WATER
CONDITIONING
4-6weeks at 20°C
CARRY – ALONG CONTROLS
Three 4-liter sea water samples from laboratory
COLLECTION
4-liter sample by seaplane
SPAWNING
Temp. raised to 25°- 30°C. for 2-3 hours; sperm added
TRANSPORT
All samples to laboratory within 3hours of collection
BIOASSAY
INNOCULATION
20-30 thousand zygotes, 1 1/2 hours old or less, added to each culture
LABORATORY CONTROLS
Equal to 10% of number of field samples
INCUBATION OF 3 REPLICATE ONE-LITER CULTURES for each field & control sample – at 20°C for 48 hours
CHLOROPHYLL ANALYSIS
500 ml.
TERMINAL SWL AND SALINITY ANALYSES
250 ml.
ALIQUOT SAMPLE
Containing 100-200 larvae
INITIAL SWL AND SALINITY ANALYSES
250 ml.
RESPONSE MEASUREMENTS
Percent abnormal larvae

FIGURE 11-2. Flow diagram of the field-sample oyster-larva response study.

(right) "carry-along controls" of seawater, taken from the laboratory water supply, were carried through the entire sampling flight to assess any changes that may have developed from transporting and handling methods.

2. At the laboratory, each field sample and each carry-along control was divided into three one-liter replicate cultures for bioassay. The remaining one-liter portion was retained for the analyses shown in the lower right of the diagram.

(lower center) 1. A number of laboratory-control cultures--equal to 10% of the number of field sample cultures--were set up, using laboratory seawater.

2. Each culture (into which a predetermined number of zygotes had been introduced) was incubated for 48 hours.

3. Following incubation, the larvae in each culture were concentrated with a sieve (35-micron mesh) and were examined with a microscope for the determination of the number of larvae with aberrant shell development.

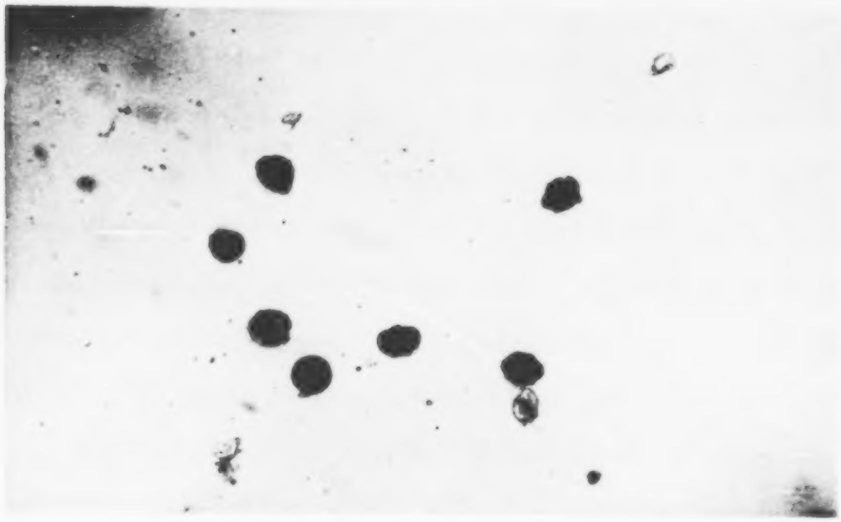
(lower left) 1. Terminal chemical analyses for SWL and salinity were done on a portion of the culture water.

A more complete description of the technique has been given by Woelke (1961b).

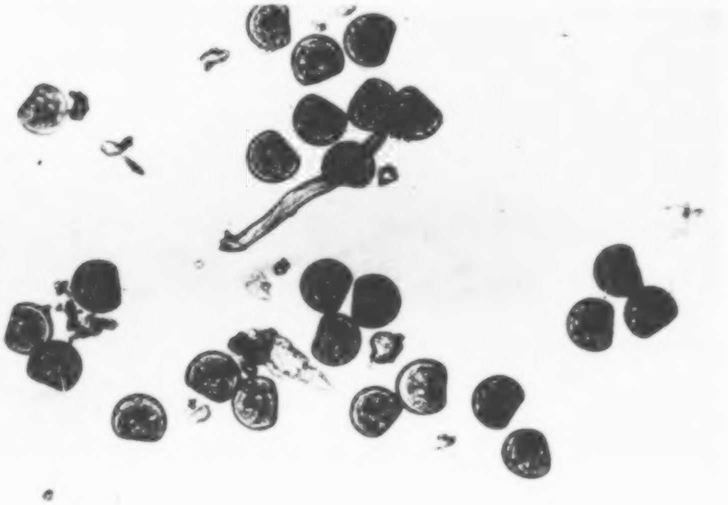
Bioassay results were reported in terms of the percent of abnormal larvae in each culture after incubation. Larvae not fully shelled (shell did not completely cover the soft body parts--Figure 11-3A) were counted as abnormal, whereas all fully-shelled larvae (Figure 11-3B) were considered to be normal, without regard to other abnormalities that might have been evident. This procedure avoided subjective interpretation in counting and provided a conservative measure. That this criterion is meaningful is attested to by the fact that repeated efforts to rear abnormal larvae to juvenile oysters have all met with failure.

All results and data from the field-sample response study were statistically analyzed by Dr. Gerald J. Paulik, Biometrician, University of Washington School of Fisheries. Descriptions of the statistical tests employed are given by Paulik in four interim reports (1963, 1964, 1965a, and 1965b) and in a final report (1966a).

Waste-Sample Study. Twenty-four-hour composite samples were collected from individual within-mill waste streams. Aliquots of these samples were analyzed for SWL, total solids (fixed and volatile), suspended solids (fixed and volatile), total sulfur, BOD_5, and COD by the same procedure described in Section 6. The samples were shipped under refrigeration to the Washington Department of Fisheries Shellfish Laboratory where they were immediately prepared for bioassay. Serial dilutions of one part waste sample to 10, 20, 100, 200, 1,000, 2,000, 10,000, 20,000, 100,000, and 200,000 parts of fresh unpolluted seawater (laboratory water supply) were made. Each dilution was divided into three replicate cultures and these were bioassayed by the same procedure used in the field-sample study. At least nine controls of fresh



(A) Abnormal, incompletely-shelled larvae with shell deformities evident and soft body-parts not completely enclosed within the shell. The evenly-rounded dark object, lower left, is not a larva.



(B) Normal, fully-shelled larvae with no evident shell deformities and soft body-parts completely enclosed within the shell.

FIGURE 11-3. Pacific oyster larvae, 48 hours old. (A) Abnormal larvae, (B) Normal larvae incubated in a water sample having an SWL concentration of 37 ppm. Courtesy of the Washington State Department of Fisheries Shellfish Laboratory.

seawater were bioassayed with each set of samples. Bioassay responses were determined in the same way as in the field-sample study. Charles E. Woelke supervised the conduct of this study and statistically analyzed and evaluated the results.

RESULTS

Results of Field-Sample Study. The results given in this section are fully presented and discussed by Paulik in a final report (1966a), unless otherwise cited. Terminal statistics derived from the analyses of the field-sample results are presented in Table 11-1. These statistics reflect the removal of all bioassay response results and chemical data:

1. from samples having salinities of 20°/oo or less--correlative tests indicate that salinities below 20°/oo adversely affect oyster-larva development and that abnormalities increase with decreasing salinity (the criterion of salinity greater than 20°/oo is conservative and provides a margin of safety);
2. from samples bioassayed during the 1963-64 winter period (October through March, inclusive); analyses showed that during this period laboratory and carry-along controls exhibited unusually high average abnormalities and unusually high variability in abnormalities among replicates, both caused by poor eggs taken from brood stock oysters which could not be conditioned properly;
3. from samples collected early on July 6, 1964, before the Georgia-Pacific and Scott mills' wastes began again after the

TABLE 11-1. Summary of results from the field-sample oyster-larva response study in the Bellingham-Anacortes area, May 1963-August 1965. Data from samples with salinities of 20°/oo or less, from samples bioassayed during the period October 1963 through March 1964, and from samples collected on July 6 and November 16 and 25, 1964, have been removed.

Station Number (1)	Number of Field Samples (2)	Mean Percent Abnormal (3)	Mean Percent Net Risk (4)	Mean SWL Conc. (ppm) (5)	Mean Salinity (°/oo) (6)	Mean Intra-Sample Variance of Percent Abnormal (7)	Inter-Sample Standard Error of Mean Percent Abnormal (8)	Standard Deviation of SWL Conc. (9)	Standard Deviation of Percent Net Risk (10)
1	5	99.80	99.80	1118.8	24.41	0.58	0.20	555.8	0.4469
2	16	91.45	91.41	244.9	25.67	2.36	6.43	328.2	25.8542
3	3	67.77	67.14	103.8	23.48	0.61	32.23	109.0	56.9110
4	20	26.10	25.16	23.8	27.39	6.03	8.05	25.8	36.5920
5	21	3.96	2.81	5.9	27.57	11.12	0.89	6.0	4.2447
6	22	2.83	1.52	3.7	27.50	4.04	0.73	4.4	3.8083
7	18	2.05	0.74	2.0	27.78	3.15	0.42	2.0	1.9271
8	20	8.53	7.42	5.8	28.14	3.14	4.48	6.4	20.2706
9	20	13.31	12.26	9.5	27.93	9.15	6.72	17.7	30.4281
10	20	20.49	19.31	14.2	26.33	3.42	7.98	22.9	36.1537
11	5	68.76	68.48	58.6	27.79	11.98	17.59	73.3	39.5916
12	15	32.93	31.87	18.6	27.08	3.71	11.50	22.6	45.2777
13	16	2.20	0.81	3.7	28.23	2.41	0.50	3.6	2.2101
14	18	28.48	27.62	110.5	28.96	3.98	10.08	344.9	43.3371
15	20	3.57	2.22	3.0	29.22	3.33	1.25	2.8	5.5313
16	9	6.12	4.91	2.2	28.22	21.11	2.62	1.4	8.2704
17	7	1.78	0.40	2.0	25.18	2.27	0.92	1.2	2.7839
18	3	2.69	1.42	0.3	28.67	16.29	1.16	0.3	2.5123
19	9	2.31	1.12	1.2	28.92	10.16	1.13	1.3	2.6135
20	16	8.98	7.44	3.9	25.97	18.82	5.61	1.4	22.8062
21	10	1.80	0.27	1.4	28.67	1.14	0.36	0.9	0.9560

July 4th holiday (with the cessation of normal waste discharges, waste concentrations in the study area were abnormally low); and

4. from samples collected on November 18 and 25, 1964, when both mills were closed by a labor strike and waste concentrations in the study area were abnormally low (see Figure 7-10).

Consequently, Table 11-1 and the treatment of the field-sample data following consider only those data (1) derived from or associated with bioassay responses not influenced by low salinity and poor test-animal stock and (2) those associated with normal mill operations; i.e., the usual ranges of water quality and environmental factors prevailing in the study area.

Column 3 of Table 11-1 gives the "mean percent-abnormal" value for each station. These response measures, together with the mean SWL values, column 5, are presented (rounded off) in Figure 11-4 to show the relationships of both to location, with respect to the two mills--the Georgia-Pacific mill and the Scott mill.

The "mean-net-risk" statistics shown in column 4 provide a slightly better measure of relative toxicity than "percent abnormal" since these values reflect the adjustment of field-sample abnormality results by the laboratory-control abnormality results for the day the field samples were collected, assuming that larval abnormalities observed in field samples were produced by environmental stresses plus experimental or laboratory stresses. However, the two statistics agree so closely that any conclusions regarding the effect of the amount

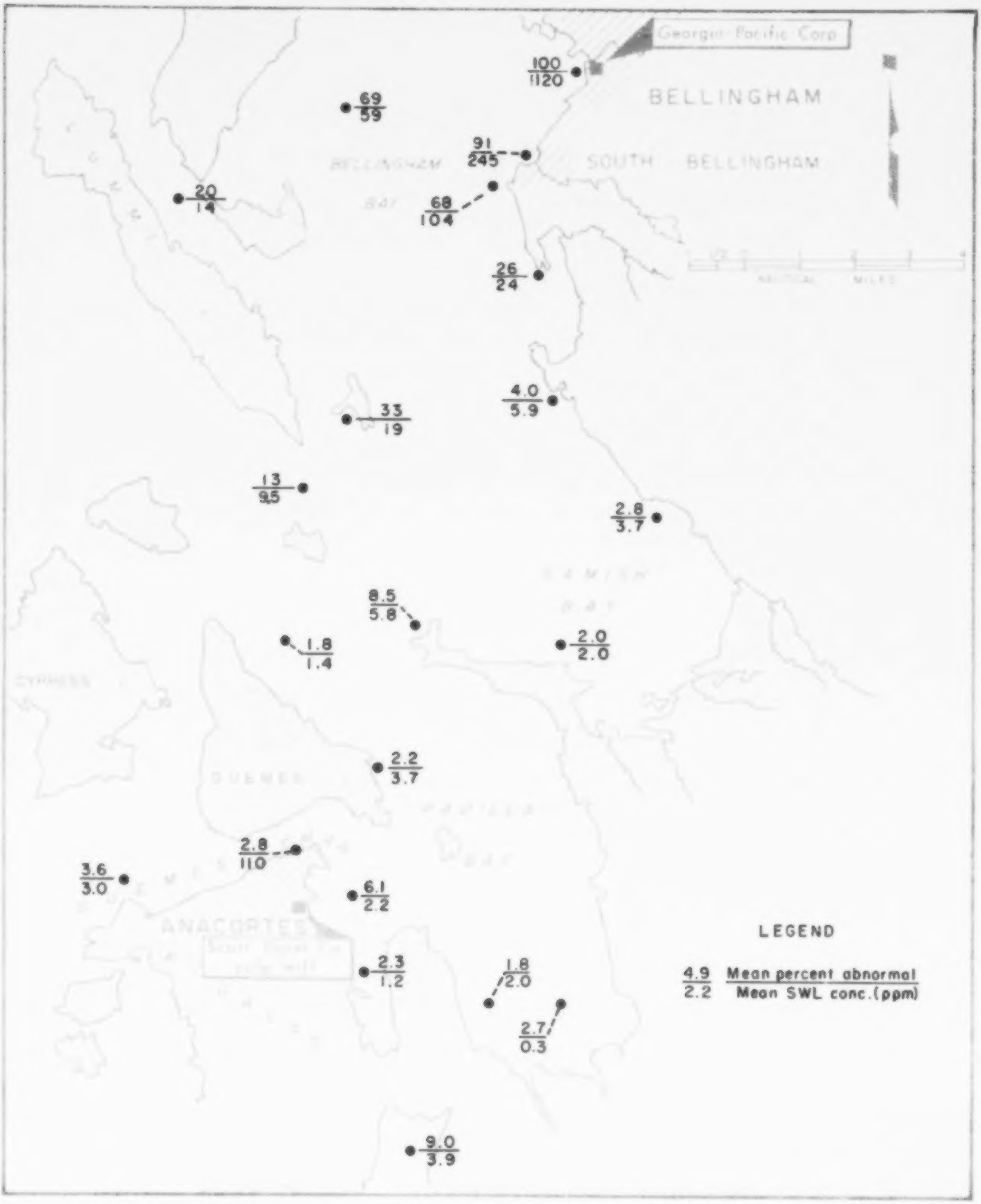

Georgia Pacific Corp
100
1120
BELLINGHAM
69
59
91
245
SOUTH BELLINGHAM
BELLINGHAM BAY
20
14
68
104
26
24
NAUTICAL MILES
4.0
5.9
33
19
13
9.5
2.8
3.7
SAMISH BAY
8.5
5.8
1.8
1.4
2.0
2.0
CYPRESS
2.2
3.7
GUEMES
PADILLA BAY
2.8
110
3.6
3.0
6.1
2.2
ANACORTES
Scott Paper Co. pulp mill
2.3
1.2
1.8
2.0
2.7
0.3
9.0
3.9
LEGEND
4.9 Mean percent abnormal
2.2 Mean SWL conc.(ppm)

FIGURE 11-4. Mean percent oyster-larva abnormality and mean SWL concentration at each field-sample station in the Bellingham-Anacortes area; field-sample oyster-larva response study, May 1963 through August 1965 (see Table 11-1 for description of data removed).

of sulfite waste liquor in the water on larval development will be the same regardless of which statistic is employed.

In Table 11-1, a definite relationship between mean percent abnormal and mean SWL concentration is seen; i.e., mean percent abnormal values increase with increases of SWL concentration. In Figure 11-4 the mean percent abnormal values are seen to increase with decreasing distance from either of the two mills. When these relationships are considered, together with the observed decreases in SWL and abnormalities that followed mill closure and the increases in SWL and abnormalities that followed mill reopenings, there can be no doubt that pulping wastes are inimical to oyster-larva development and that the two mills named are the sources of these damaging wastes.

Larval Abnormality vs. SWL Concentration. Figure 11-5 presents the relationship between percent abnormal and SWL concentration. The formula parameters of the logistic curve shown were estimated by an iterative non-linear weighted least-squares technique. All results, excluding those associated with low salinity, 1963-64 winter bioassays, and mill-closure sampling described above, were grouped into SWL intervals of the geometric progression, 0-5, 4-8, 8-16 ppm, etc., and the mean percent-abnormal and mean SWL values of each of these intervals were used to supply the data for this curve. Note that larval abnormality begins to increase very rapidly at SWL concentrations around 10 ppm, and that near-100% abnormality is reached at about 60 ppm SWL.

Larval Abnormality in Controls. Laboratory controls employed unpolluted seawater from the Laboratory's water supply. Consequently, larval abnormalities noted in these controls are taken to be responses

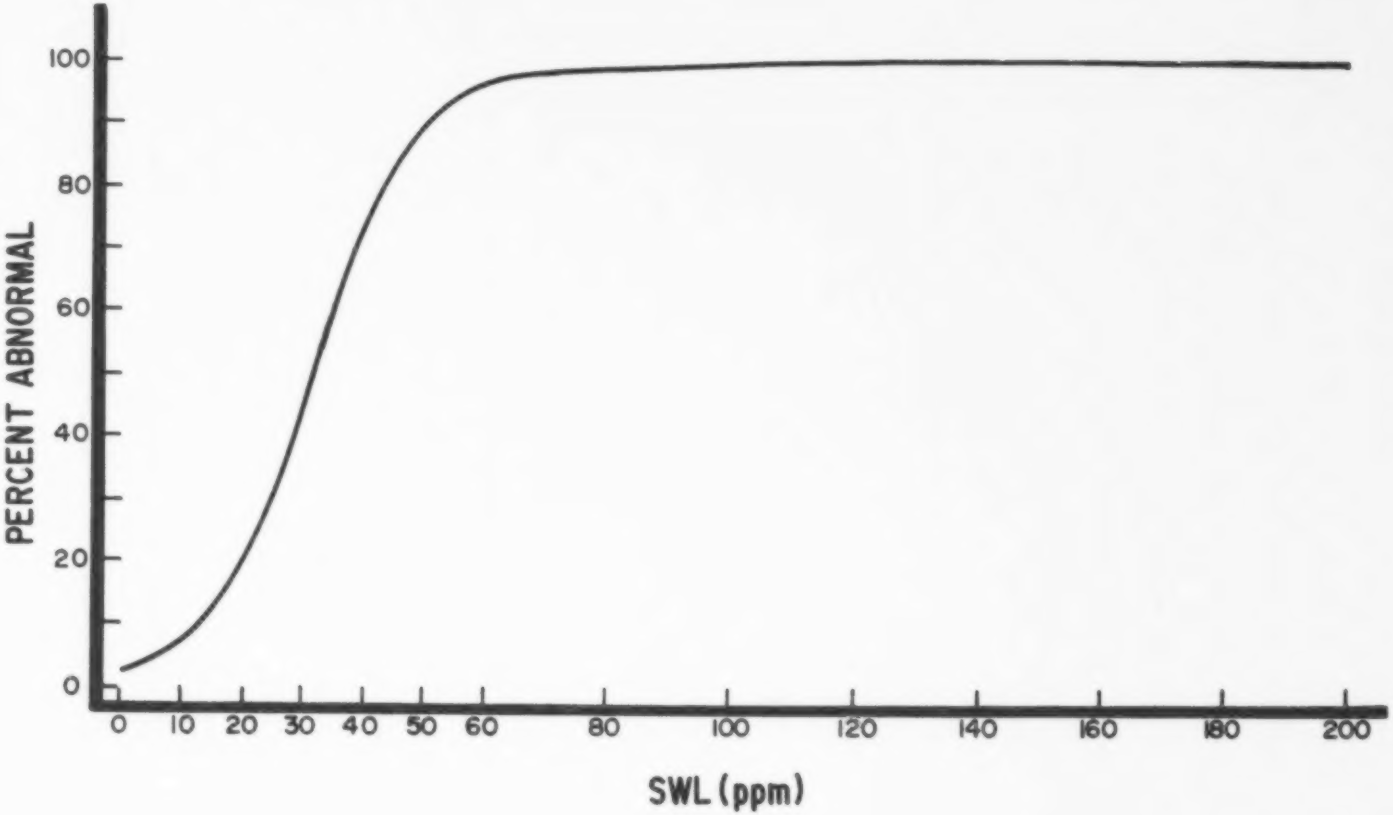


FIGURE 11-5. Percent larval abnormality vs. SWL, for the Bellingham-Anacortes area.

to experimental stresses. Carry-along controls utilized the same water source, but these were carried in the airplane during the collection of field samples. Abnormalities observed in these controls are taken to measure experimental stresses plus any stresses attributable to alteration of the sample water through sample handling and transportation. A third set of controls, field controls, was arbitrarily defined as all field samples that met all of the three criteria: (1) had salinities of greater than $20^{o}/oo$, (2) were not collected during the 1963-64 winter period when poor test animals were used, and (3) had SWL concentrations of 2.0 ppm and less. The bases for criteria 1 and 2 have been given and the bases for criterion 3 are that SWL concentrations of 2.0 ppm and less, as measured by the Pearl-Benson test, are background levels and indicative of little or no concentrations of pulping wastes and that earlier analyses indicated that the bioassay test was not affected by any of the measured environmental factors except SWL (and low salinity).

Table 11-2 presents the mean percent-abnormal values for each of these controls for each month and for the entire study. Note that overall means of control abnormals (bottom row) are about 2% and significantly lower than the mean abnormal values found at stations where above-background concentrations of SWL were observed (Table 11-1). Note also that the field-control and carry-along-control abnormalities are not significantly different from the laboratory-control abnormalities. This indicates that the study techniques used were sensitive and valid for detecting the effects of pulping wastes on oyster-larva development.

TABLE 11-2. Summary of the percent-abnormal values in the control bioassays of the field-sample oyster-larva response study in the Bellingham-Anacortes area, May 1964 through August 1965. Data collected October 1963 through March 1964 excluded.

	Field Controls (SWL ≤ 2 ppm, Salinity > 20°/oo)		Laboratory Controls	Carry-along Controls
Month	No. of Samples	Mean % Abnormal	Mean % Abnormal	Mean % Abnormal
May 1963	7	5.55	0.69	-
June	11	1.67	1.23	4.48
July	13	2.05	1.91	0.43
Aug.	-	-	1.10	0.79
April 1964	2	0.71	0.46	0.34
May	1	10.77	4.16	6.74
June	1	0.19	0.19	2.22
July	9	2.31	1.17 1/	0.96 1/
Aug.	10	2.98	0.13	-
Sept.	4	1.90	3.27	2.02
Oct.	7	1.55	2.21	3.79
Nov.	18	1.09	2.24 2/	4.14 2/
Dec.	6	2.09	2.53	0.93
Jan. 1965	2	3.16	3.34	2.75
Feb.	7	0.46	0.97	0.18
March	8	1.13	0.44	0.81
April	5	0.78	0.35	1.03
May	4	3.95	0.75	2.99
June	4	1.42	0.69	0.66
July	7	4.95	0.69	0.80
Aug.	3	1.37	0.69 3/	-
Over-all Mean (weighted)		2.17	1.47	2.19

1/ Three samples
2/ Four samples
3/ Two samples

Larval Abnormality During Mill Closure. During the period of November 12-26, 1964, a labor strike stopped production and the discharge of wastes at both the Georgia-Pacific and the Scott mill. The results from samples collected during this period on November 25, together with results from the regular sampling dates, October 27 and November 30, that preceded and followed this period, are given in Table 11-3. Note that SWL concentrations decreased between October 27 and November 25 and increased between November 25 and November 30. The probabilities that these decreases and subsequent increases were due to chance are less than 0.5% (one-sided distribution-free sign test--Paulik, 1965a and 1965b). Hence, the null hypothesis that mill operations were not responsible for these changes is rejected. Note also that percent-abnormal values decreased between October 27 and November 25 and then increased between November 25 and November 30. The probabilities that these decreases and subsequent increases were due to chance are less than 2.5% and 0.5%, respectively (loc. cit.). Therefore, the null hypothesis that mill operations were not responsible for the observed changes in abnormalities among the dates considered, also, is rejected. Results obtained from samples collected on the mill-closure date of July 6, 1964, as compared with results from June 23 and July 9, 1964, show similar relationships.

Figure 11-6 shows the percent-abnormal and SWL values for November 25 in relationship to location with respect to the two mills. The near-complete flushing of pulping wastes from the Bellingham system that had been accomplished by this date (see Figure 7-10) resulted in the low levels of abnormality noted.

TABLE 11-3. Percent-abnormal and SWL values for samples collected at selected stations in the Bellingham-Anacortes area on October 27, November 25, and November 30, 1964--before, during, and after mill closure, respectively.

	October 27, 1964		November 25, 1964		November 30, 1964	
Station	SWL (ppm)	Percent-Abnormal	SWL (ppm)	Percent-Abnormal	SWL (ppm)	Percent-Abnormal
2	190	100.0	5	0.2	62	100.0
4	6	2.3	< 1	0.2	< 1	2.2
6	4	1.3	0	0.3	0	1.2
7	2	0.9	< 1	0.2	-	-
8	1	2.9	0	0.6	-	-
13	< 1	2.1	0	0.8	-	-
9	1	1.0	0	1.6	< 1	2.7
12	1	1.7	0	0.6	1	2.8
10	8	2.4	1	2.0	4	2.7
15	1	1.0	0	0.7	1	2.4
14	-	-	< 1	0.5	270	100.0

Notes: Larval response results from Station 1 on November 25 and 30 were affected by salinities of less than 10^{o}/oo; hence, are not given.

Results obtained from samples collected on November 16, during the closure period, at many stations showed lower percent-abnormal and SWL values than those collected on either October 27 or November 30.

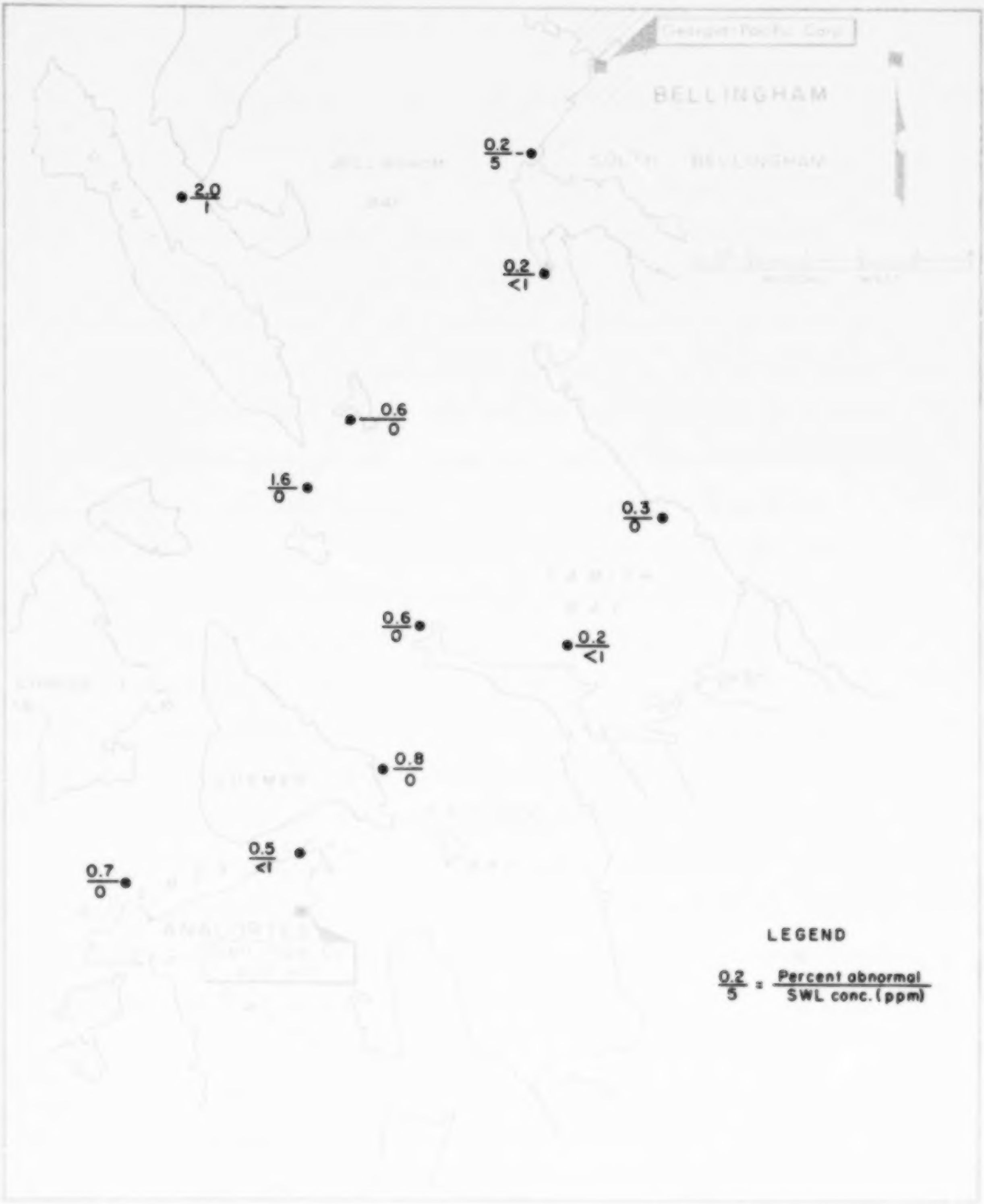

Georgia-Pacific Corp.
BELLINGHAM
BELLINGHAM BAY
SOUTH BELLINGHAM
0.2 / 5
2.0 / 1
0.2 / <1
0.6 / 0
1.6 / 0
0.3 / 0
SAMISH BAY
0.6 / 0
0.2 / <1
0.8 / 0
0.5 / <1
0.7 / 0
ANACORTES
LEGEND
0.2 / 5 = Percent abnormal / SWL conc. (ppm)

FIGURE 11-6. Percent-abnormal values and SWL concentrations from samples collected at selected stations in the Bellingham-Anacortes area on November 25, 1964.

Results of the Waste-Sample Study. Results given below are fully presented and discussed by Woelke in a report to the Project (1965, unpublished).

For each waste sample, percent-abnormal values from the several dilutions were plotted on probit paper against the appropriate dilution ratios and SWL concentrations. From the line of best-fit, dilution ratios and SWL values for the 0, 20, 50, and 100% abnormal levels were determined. These data are shown in Table 11-4. Note that SWL concentrations do not comparatively measure the relative toxicity of the several wastes tested; e.g., the dilutions of alcohol plant wastes and pulp washing-screening wastes that produced no abnormality had about-equal SWL concentrations, yet the former waste is about 20 times more toxic than the latter, as evidenced by a comparison of the dilution ratios. This was not unexpected; SWL concentration, as determined by the Pearl-Benson test, is merely a measure of the relative intensity of the color complex formed by sulfonated lignins and test reagents. Whereas the test may representatively measure the concentrations of lignins and hence, the relative concentrations of sulfite waste liquors, it does not measure the relative concentrations of the toxicant(s) that interfere with oyster-larva development. Quite clearly, in comparing the relative toxicity of various within-mill waste streams, the values of dilution ratio must be used.

It is seen in Table 11-4 that alcohol plant wastes are the most toxic of those several waste streams generated by the Georgia-Pacific complex at Bellingham (both the pulp and board mill and the paper mill). Next in level of toxicity are the bleach plant wastes and the pulp

TABLE 11-4. Dilution ratios and SWL concentrations of waste dilutions which produce 0, 20, 50, and 100% abnormal oyster larvae; for wastes collected from sources i the Bellingham-Anacortes area.

Waste Stream	No Abnormality		20% Abnormality		50% Abnormality		100% Abnormality		Mean Percent Abnormal in Laboratory Controls
	SWL (ppm)	Dilution Ratio	SWL (ppm)	Dilution Ratio	SWL (ppm)	Dilution Ratio	SWL (ppm)	Dilution Ratio	
Georgia-Pacific pulp and board mill									
Alcohol plant (sewer 3)*	18	1:20,000	19	1:19,000	24	1:16,500	43	1:10,000	2.2
Bleach plant (sewer 5)	4	1:2,000	8	1:920	13	1:600	36	1:200	2.2
Pulp washing and screening (sewer 4)	< 18	1:1,000	29	1:620	41	1:450	97	1:200	2.2
Board mill (sewer 1)	4	1:1,000	14	1:72	20	1:50	50	1:20	2.2
Hydraulic barker (sewer 2)	5	1:100	14	1:22	18	1:17	30	1:10	2.2
Georgia-Pacific paper mill									
Total waste flow	0	1:100	> 4	>1:10	> 4	>1:10	> 4	>1:10	2.7
Scott mill-Anacortes									
Total waste flow	2	1:100,000	14	1:3,400	24	1:1,950	301	1:200	0.1
Shell oil refinery									
Total waste flow	0	1:20	> 0	>1:10	> 0	>1:10	> 0	>1:10	3.4
Texaco oil refinery									
Total waste flow	1	1:100	1	1:18	1	1:15	1	1:10	3.4

* See Figure 6-1.

washing-screening wastes; both have about the same effect on oyster larvae. Least toxic are the board mill, hydraulic barker, and paper mill wastes. Accordingly, these results evidence the relationship that the toxicity of a waste increases as its proportional content of strong pulping wastes (sulfite waste liquors of the cooking process) increases. Hence, pulp washing-screening wastes which contain lesser amounts of cooking liquors are less toxic than alcohol wastes, etc.

Wastes discharged by the Scott mill at Anacortes include strong pulping wastes and, as noted above, such wastes are highly toxic. Wastes discharged by the two oil refineries at Anacortes have a very low toxicity.

To better illustrate the toxic effects of the waste streams considered in Table 11-4, the amounts of dilution water required to reduce the toxicity of each to non-harmful levels (no larval abnormality) were computed and are tabulated in Table 11-5. Note that considerable amounts of dilution water are required for the alcohol plant, bleach plant, and pulp-washing-screening wastes produced by the Georgia-Pacific pulp and board mill. However, the weak and variable currents and circulation patterns in Bellingham Harbor and Bellingham Bay do not immediately provide these amounts of water. Consequently, dispersion and mixing of these wastes throughout all of the surface waters of the study area are required to effect adequate dilution.

Considerable amounts of dilution water also are required by the Scott mill waste discharge. However, the large volumes of tidal flow passing through Guemes Channel more nearly satisfy this requirement. Relatively low volumes of dilution water are required to alleviate the toxic effects of paper and board mill wastes, barker wastes, and oil refinery wastes.

TABLE 11-5. Dilution water required to reduce the toxicity of Bellingham-Anacortes area wastes such that they would have no effect on oyster-larva development.

Waste Stream	Waste Flow* (mgd)	Dilution Water Required for no Abnormality (cfs)**
Georgia-Pacific pulp and board mill		
Alcohol plant	2.74	84,800
Bleach plant	13.20	41,000
Pulp washing and screening	17.30	26,800
Board mill	1.13	1,750
Hydraulic Barker	1.43	220
Georgia-Pacific paper mill	5.30	820
Scott mill-Anacortes	5.67	877,000
Shell oil refinery	2.1	65
Texaco oil refinery	3.0	460

* Average flow rate for the period when samples were collected in million of gallons per day.

** Cubic feet per second (one cfs is equal to 643,317 gallons per day).

DISCUSSION

Results presented in Table 11-2 clearly show that field samples having SWL concentrations between 0 and 2 ppm produce oyster-larva abnormalities of about 2%. Such abnormalities are not significantly different from those experienced in laboratory and carry-along controls. Therefore, it is concluded that such levels of SWL and percent abnormal are representative of non-polluted conditions. This conclusion is supported by data collected on November 25, 1964 (see Figure 7-10 and associated text, Table 11-3, and Figure 11-6). On this date, after 13 days of flushing had acted to remove pulping wastes from the study area, SWL concentrations were less than 2 ppm (except in the northeastern corner of Bellingham Bay), and percent-abnormal values were equal to or less than 2% throughout the study area.

At SWL concentrations greater than 2 ppm, increasing oyster-larva abnormalities are detected. Abnormalities are slightly above control levels at SWL concentrations between 2 and 8 ppm, are significantly greater than control levels at SWL concentrations between 8 and 16 ppm, and increase to exceedingly higher levels at SWL concentrations greater than 16 ppm (Figure 11-5). Accordingly, the conclusions of the study are:

1. Complete protection for oyster larvae can only be obtained by permitting no SWL concentrations greater than 2 ppm (as attributed to pulping wastes).

2. Slight damage to oyster-larva populations occurs at low levels of waste concentration; *viz*., 2 to 8 ppm SWL. At these levels, percent oyster-larva abnormals average 4.13. The 95% confidence range interval for this mean is 2.54% to 6.07%.
3. Significant damage to oyster-larva populations occurs at the higher waste levels of 8 to 16 ppm SWL. At these levels, the mean percent abnormal is 5.87 (the 95% confidence range interval for this mean is 1.25% to 10.48%). This conclusion agrees with that reached by Gunter and McKee in their review of literature (1960); *i.e.*, SWL concentrations of 8 to 16 ppm represent the threshold of toxicity for Pacific oyster larva.
4. Excessive injury to oyster larvae takes place at SWL concentrations greater than 16 ppm. Above 16 ppm SWL, the mean percent abnormal is 76.13. The 95% confidence range interval for this mean is 67.59% to 84.66%.

Referring to Table 11-1 and Figure 11-4 in consideration of the above conclusions, it is seen that (1) excessive damage to oyster larvae prevails throughout northern Bellingham Bay (north of the southern tip of Lummi Island) and in Guemes Channel in the vicinity of the Scott mill waste discharge, (2) significant damage occurs in the region of Bellingham Bay between Lummi and Guemes Islands, and (3) slight damage to oyster larvae occurs throughout the remaining parts of the Bellingham-Anacortes area with the exception of the southeastern portion of Samish Bay and the southern portions of Padilla and Fidalgo Bays where little damage was detected. Summarily, it is seen that pulping wastes, particularly from the Georgia-Pacific mill, have caused water quality throughout the largest part of the Bellingham-Anacortes area to be inimical or less than satisfactory for the proper development of Pacific oyster eggs and larvae.

Results in Tables 11-4 and 11-5 and in the associated text indicate that strong pulping wastes--digester wastes, including the alcohol plant wastes from the Georgia-Pacific mill--are the principal causes of the above described damages. Clearly, treatment of these strong wastes is indicated for the protection of shellfish life in the study area. As is indicated above, treatment of strong pulping wastes by the Georgia-Pacific mill will partially but not completely eliminate the presently prevailing adverse effects of mill wastes on shellfish life. To accomplish complete protection for oyster larvae and other sensitive early-life forms, it is suggested that suitable treatment of the weaker mill wastes--pulp washing-screening and bleaching wastes, in particular--will have to be accomplished in addition to the treatment of strong pulping wastes.

12. FLATFISH EGGS

Other planktonic early-life stages occurring in the Bellingham study area are those of the several species of flounders (mostly Pleuronectidae) common to Puget Sound. The commercially most important of these is the English sole (Ward, Robison, and Palmen, 1964). These fish tend to seek out and spawn in embayments, such as Bellingham Bay. When fertilized, the eggs of these fishes float, and subsequent embryonic and larval development takes place in the near-surface waters. It is in this surface zone, however, that the sensitive early-life stages are most apt to encounter concentrations of pulp mill wastes, and there is evidence that they are injured by the toxicity of these wastes. For this reason, English sole egg studies were conducted to determine (1) the distribution and abundance of English sole eggs in the Bellingham study area, and the associated water quality, and (2) the relationship between the injury caused and the strength of the dispersed pulp mill wastes.

STUDIES

English Sole Egg Distribution Study. Studies of the occurrence and distribution of English sole eggs in Bellingham Bay were conducted from January through March 1966. English sole eggs and associated water quality were sampled on four occasions from ten selected stations in Bellingham Bay.

English Sole Egg Bioassay Study. The investigation consisted of laboratory bioassays conducted during the period of January through

April 1965. In the study, English sole eggs were fertilized in the laboratory and then incubated for about seven days in dilutions of sulfite waste liquor (SWL) ranging in strength from 6 to 1,000 ppm SWL. After incubation, the eggs and larvae (yolk-sac fry) were examined under a microscope to determine response--either injury or retarded development--to the various concentrations of SWL. The study was conducted by Project personnel at the Friday Harbor Laboratories of the University of Washington.

METHODS

Egg Distribution Study Methods. Fish eggs were collected at ten stations in northern Bellingham Bay (Figure 12-1) at depths of 1, 17, and 33 feet. Three half-meter nets, with a mesh aperture of 0.55 mm, were towed simultaneously at 3 knots for five minutes. The plankton samples thus collected were preserved in Stockard's solution and sent to the laboratory where the English sole egg fraction was removed. The volume of English sole eggs in each sample was measured in a 15-ml centrifuge tube. Simultaneous water samples were taken with Nansen bottles from the three depths just prior to each tow and analyzed for salinity and SWL by standard procedures.

Bioassay Study Methods. Mature English sole were captured by dragging an otter trawl from the R/V HAROLD W. STREETER in Port Madison, Port Discovery, and Holmes Harbor (Figure 12-2)--areas unaffected by discharges of pulp and paper mill wastes. Ripe fish were not found earlier than January 18 nor later than March 22. Captured fish were emptied directly into a water-filled tank and sorted underwater. Selected fish were transferred gently to a circulating seawater live

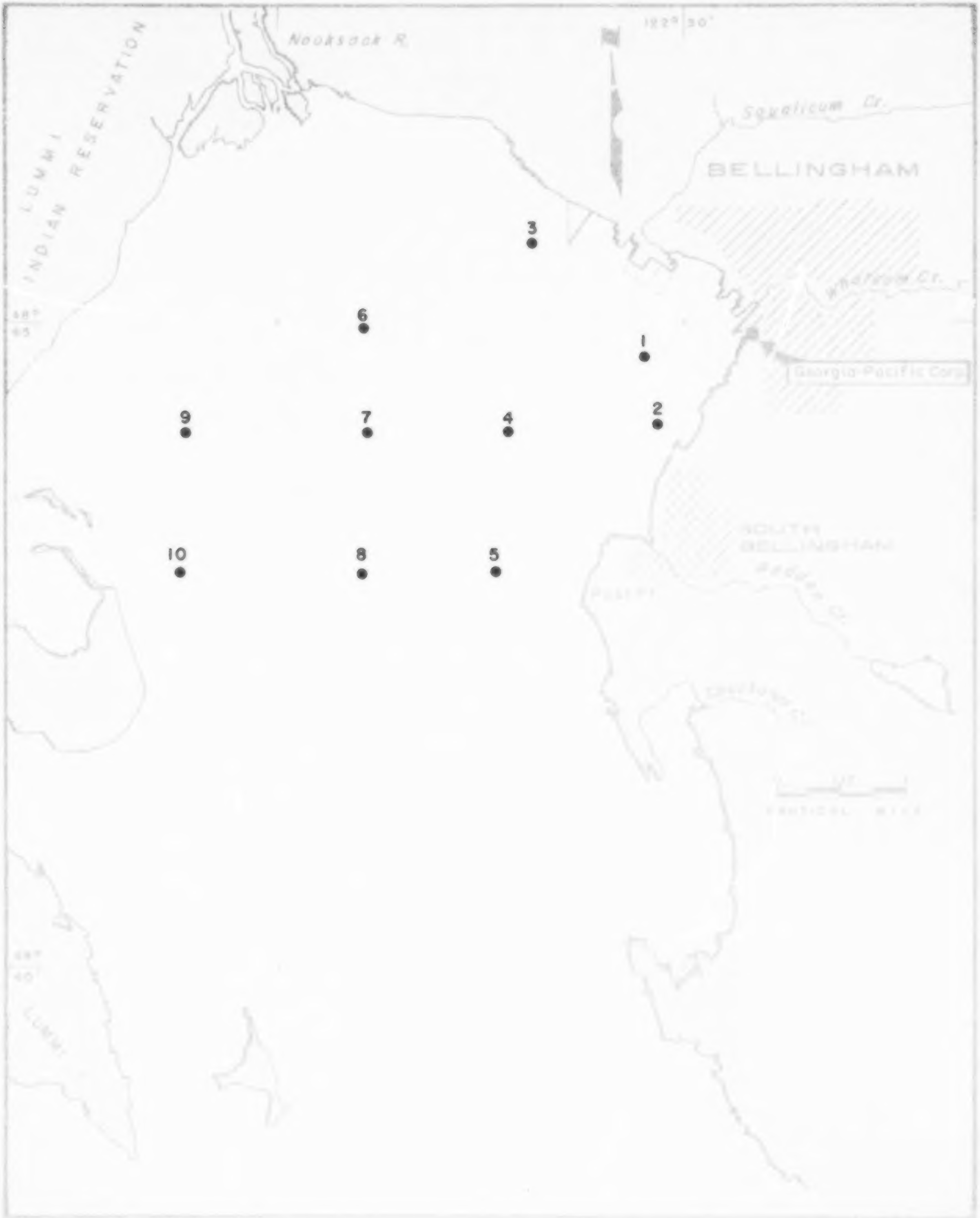

Nooksack R.
122°30'
LUMMI INDIAN RESERVATION
Squalicum Cr.
BELLINGHAM
Whatcom Cr.
48°45'
Georgia-Pacific Corp.
SOUTH BELLINGHAM
Padden Cr.
48°40'
LUMMI
3
6
1
9
7
4
2
10
8
5

FIGURE 12-1. Station locations in the Bellingham area at which flatfish eggs were collected and water quality was determined.

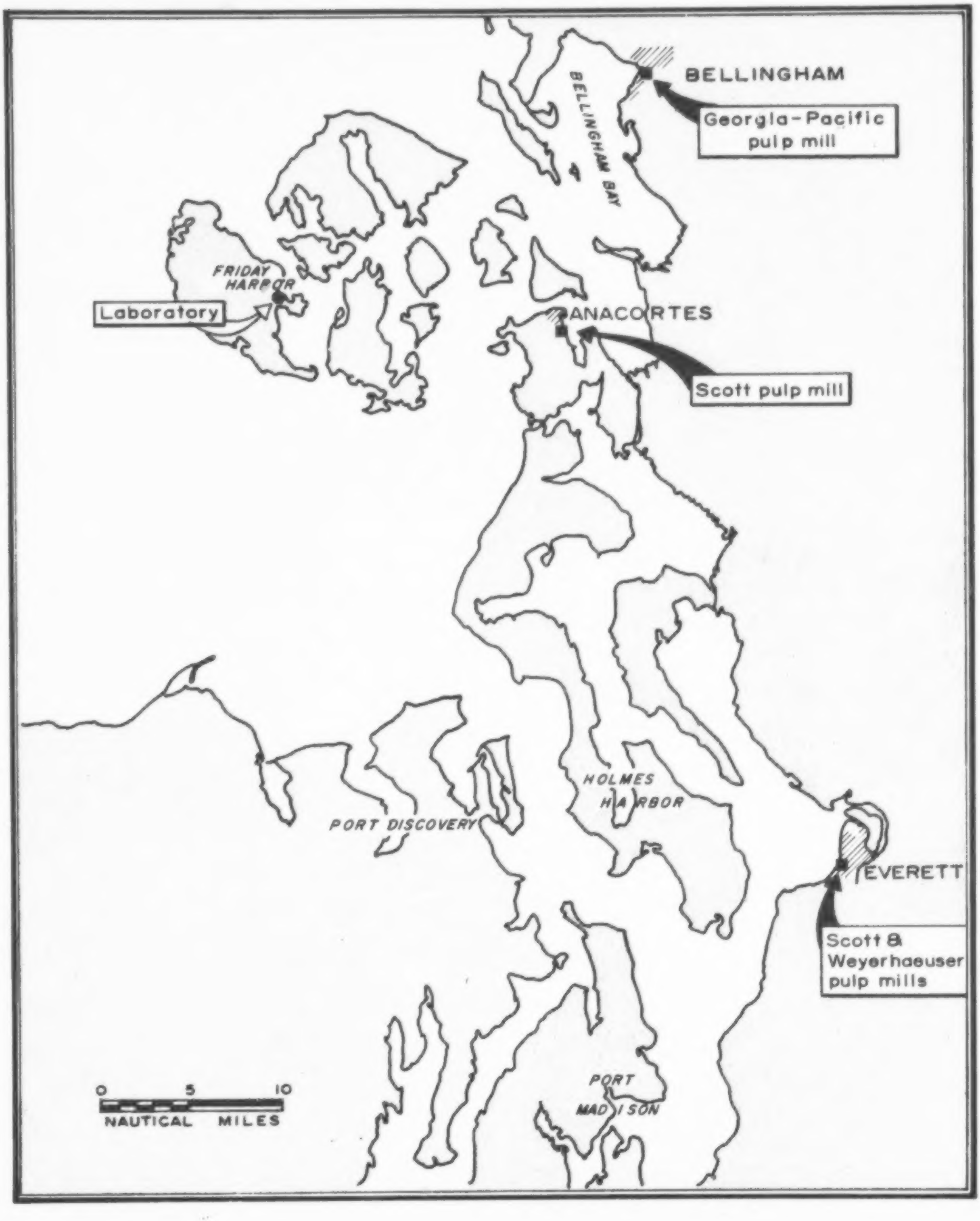

BELLINGHAM
BELLINGHAM BAY
Georgia-Pacific pulp mill
FRIDAY HARBOR
Laboratory
ANACORTES
Scott pulp mill
HOLMES HARBOR
PORT DISCOVERY
EVERETT
Scott & Weyerhaeuser pulp mills
PORT MADISON
0 5 10
NAUTICAL MILES

FIGURE 12-2. Spawning areas from which parent stock of English Sole were taken for the flatfish egg study.

tank on the deck of the STREETER and transported to the laboratory. Fish were never held on board longer than 24 hours, and mortalities were remarkably few. In the laboratory, fish were separated by sex and kept in circulating seawater tanks. Only fresh, ripe fish which had been kept less than a week and which had reached maturity prior to capture were used as parent fish.

Twenty-four hour composite samples of sulfite waste liquor were supplied by the Scott Paper Co. from their Anacortes mill. These samples were received at the laboratory approximately 24 hours after being drawn. On arrival at the laboratory, they were placed in the fume hood and ventilated for an additional day. Hence, all samples bioassayed were at least 48 hours old. After stabilization, each sample was analyzed for SWL and then serially diluted with fresh, filtered seawater to form stock solutions of 10,000, 1,000, and 100 ppm SWL (based on 10% solids). These stock solutions were further diluted to form seven test solutions in a logarithmic series of concentrations: 5.6, 13.5, 32, 75, 180, 420, and 1,000 ppm SWL.

One each of the seven test solutions and three replicate controls (seawater) were tested in each of the six bioassays. The amount of raw wastes in any test solution never exceeded 1.5% of the total volume so that the salinity (32^{o}/oo throughout the study) and other colligative properties of the native diluting seawater were preserved. The dilution water itself was drawn from the all-glass seawater system of the Friday Harbor Laboratories.

After preparation, samples were drawn from each test solution for the determination of SWL (Barnes, et al.; 1963); DO by a Beckman oxygen electrode, Model 777; and pH by a Beckman Zerometric pH meter.

Two-liter, wide-mouth, flintglass jars were used as incubation vessels. During the bioassay, each vessel was gently stirred by slowly bubbling with air through a glass tube (A.P.H.A., 1962). Incubation temperature was stabilized by placing the vessels in a water bath being circulated with seawater at ambient sea-surface temperature, 8°C throughout the experiments.

One thousand ml of each test solution were put into each incubation vessel and brought to bioassay temperature in the water bath. As suggested by Oppenheimer (1955), antibiotics (50 ppm each of penicillin G and streptomycin sulfate) were added to prevent bacterial infection of the eggs and to preserve the initial concentration of SWL. Preliminary checks and other experimental evidence indicated that this concentration and combination of antibiotics was effective for these purposes without adversely affecting the eggs or larvae.

Ripe eggs and sperm were stripped directly from the parent fish into a shallow vessel of chilled seawater. After 15 minutes, the majority of eggs were fertilized and rose to the surface. About 200 fertilized eggs were transferred to each control and test vessel. The approximate number transferred was determined by Sedgwick-Rafter cell count of a similar sized aliquant. The eggs were incubated until 24 hours after larvae appeared in the control vessels. The eggs and larvae were removed from the solutions, concentrated by filtration through #6 bolting cloth, anesthetized in MS 222 (tricaine methanesulfonate) to minimize deformation, and fixed in 1% formalin. The pH and DO of the test solutions were determined at the end of the experiment for comparison with the initial measurements of these properties. No significant changes in pH or DO were ever observed.

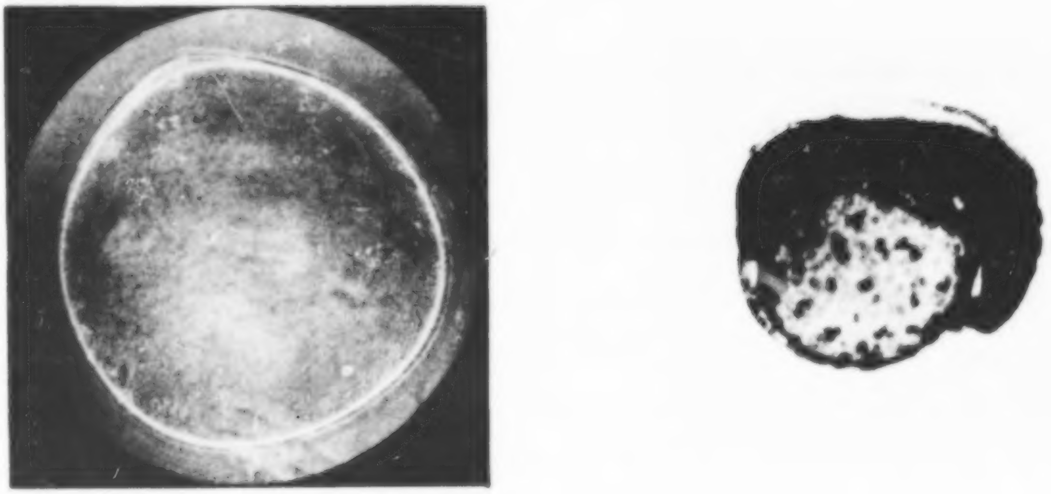
The eggs and larvae were examined under a dissecting microscope, and total counts of the forms in each of the following categories were made:

1. Dead eggs - no embryonic development apparent (Figure 12-3A).
2. Developing eggs - intact eggs containing embryos; no indication of hatching (Figure 12-3B & C).
3. Transitional larvae - those larvae still having ventral flexure or parts of the shell adherent (Figure 12-3D).
4. Normal larvae - (Figure 12-4A).
5. Abnormal larvae - those larvae showing serious deformities or flexures (Figure 12-4B, C, & D) considered anomalous by Polikarpov Ivanov (1961) and Dr. Allyn H. Seymour, Professor of Fisheries, Univ. of Washington, Seattle (personal communication).
6. Uncertain - those larvae considered unclassifiable.

RESULTS

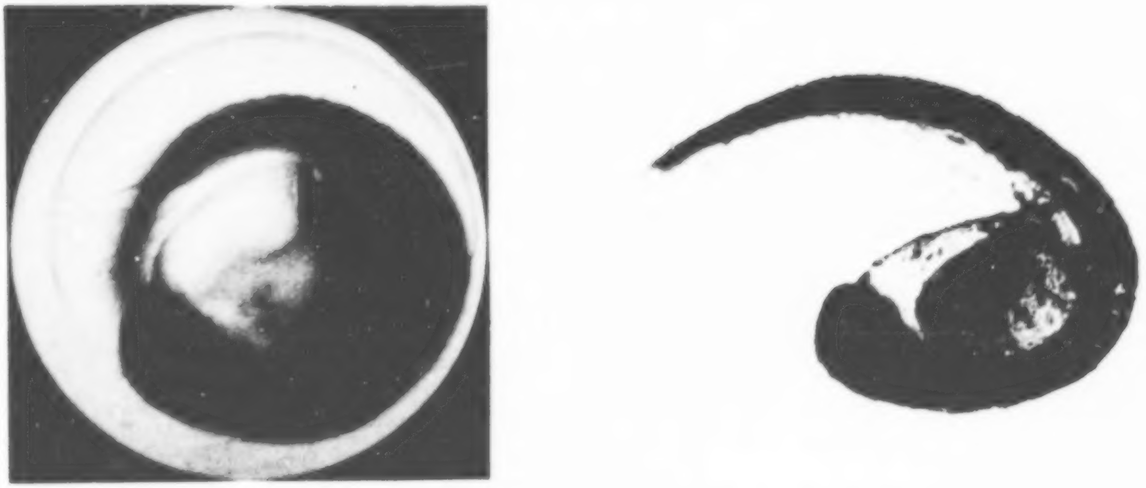
It was found that significant numbers of English sole eggs were present in the surface waters of Bellingham Bay during the peak of the reproductive season (Table 12-1). It is important to note that large numbers of eggs occur (1) in waters with high SWL concentration, and (2) in waters of a specific gravity less than that of the eggs (1.022).

Sulfite waste liquor, even when dilute, is severely damaging to developing English sole eggs. The deleterious effects of SWL range from the ultimate damage of killing the eggs to the relatively subtle damage of delaying hatching time. The results presented here are average values based on the six bioassays.



(A) Dead egg. No apparent embryonic development.

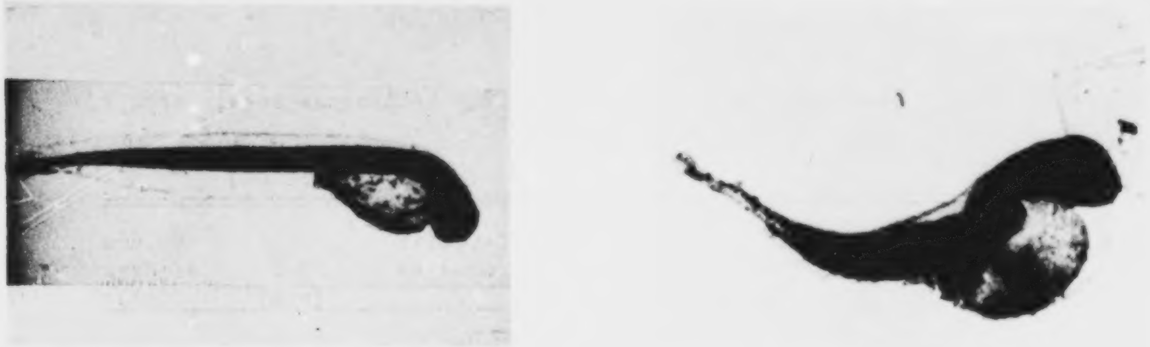
(B) Developing egg. Limited embryonic development; frequently observed.



(C) Developing egg. Embryonic development virtually complete.

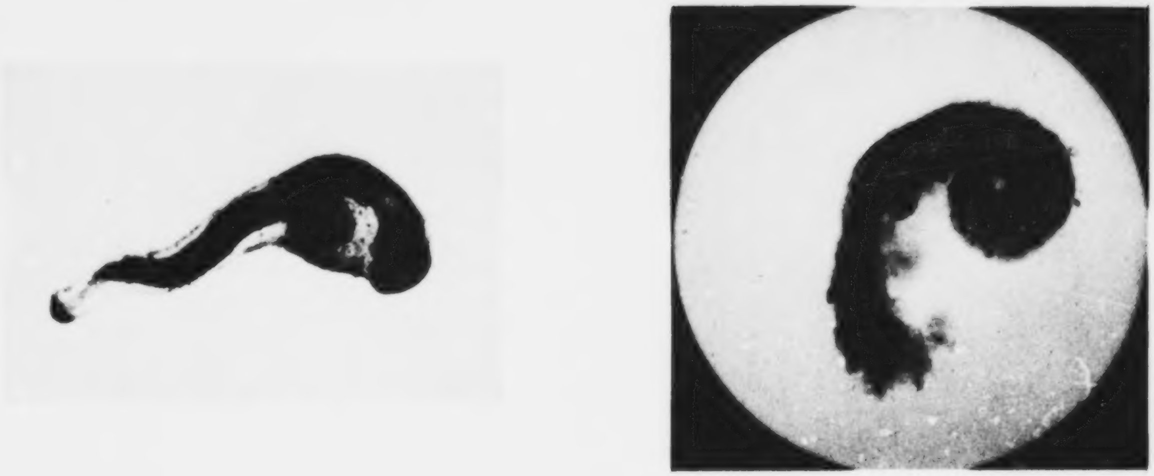
(D) Transitional fry. The organism has hatched, but has not yet straightened.

FIGURE 12-3. Four observed stages of development of English sole eggs after about seven days' incubation in test and control solutions.



(A) Normal fry.

(B) Abnormal fry. Most frequently seen deformity.



(C) Abnormal fry.

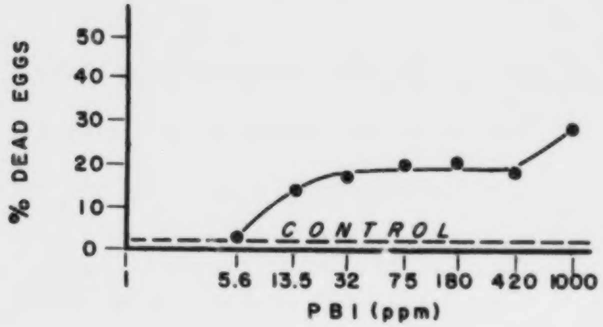
(D) Abnormal fry. Another kind of deformity frequently seen.

FIGURE 12-4. Four observed stages of development of English sole eggs after about seven days' incubation in test and control solutions.

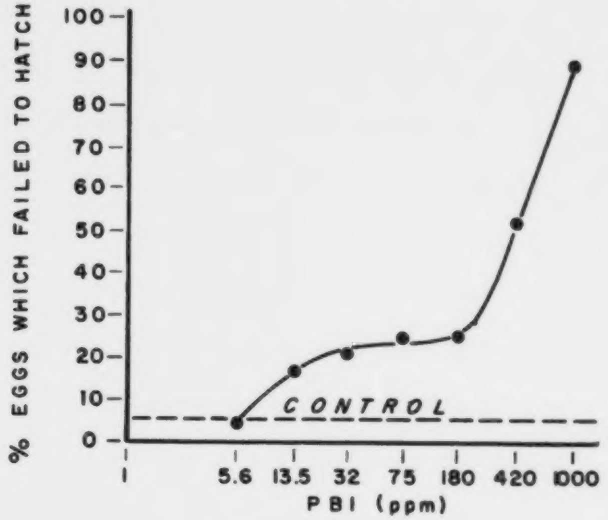
TABLE 12-1. Flatfish egg distribution in the Bellingham area; March 2, 1966.

Station	Depth (ft.)	Temp. (^oC)	Salinity ($^o/oo$)	Specific Gravity	SWL (ppm)	Volume of Eggs (ml)*
1	1	6.6	25.5	1.0200	55	0.9
	17	7.1	26.8	1.0210	19	0.5
	33	7.1	27.0	1.0211	12	1.0
2	1	6.6	23.7	1.0186	179	1.8
	17	6.8	27.0	1.0212	51	1.8
	33	7.1	27.0	1.0211	9	0.5
3	1	5.5	24.2	1.0191	175	0.5
	17	6.6	26.9	1.0211	106	0.5
	33	6.6	27.0	1.0212	20	5.5
4	1	6.2	25.2	1.0198	83	5.8
	17	6.6	26.7	1.0210	28	1.0
	33	7.0	27.3	1.0214	13	0.7
5	1	6.4	25.4	1.0200	94	1.7
	17	6.7	27.2	1.0214	25	0.6
	33	7.0	27.4	1.0215	11	0.6
6	1	4.5	19.8	1.0157	61	1.3
	17	6.3	26.0	1.0205	35	1.6
	33	6.5	26.4	1.0207	8	0.9
7	1	5.6	24.4	1.0193	60	3.5
	17	6.5	26.8	1.0211	41	2.1
	33	6.8	27.6	1.0217	18	0.5
8	1	6.1	25.0	1.0197	83	3.5
	17	6.8	27.0	1.0212	34	0.8
	33	6.9	27.1	1.0213	17	0.8
9	1	5.0	21.3	1.0169	73	0.5
	17	6.7	26.3	1.0206	60	4.3
	33	6.7	28.9	1.0227	16	0.7
10	1	4.9	22.5	1.0178	69	0.3
	17	6.5	26.5	1.0208	64	10.0
	33	6.7	27.3	1.0214	10	1.5

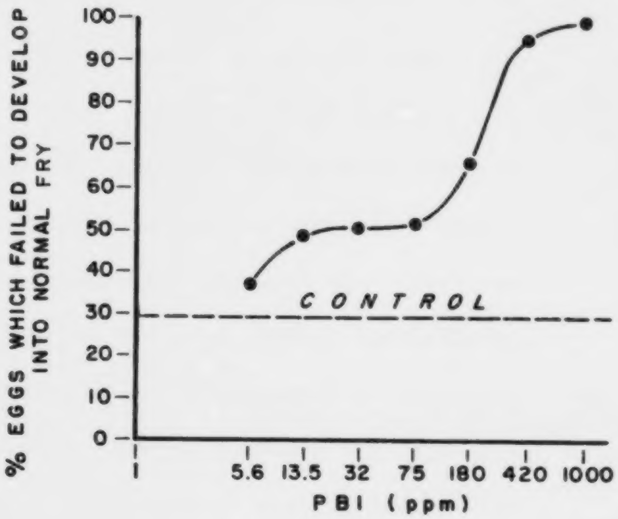
* One ml contains approximately 1,000-1,200 fertilized English sole eggs.



(A) Percent of eggs killed during incubation.



(B) Percent of eggs which failed to hatch within normal incubation period.



(C) Percent of eggs which failed to develop into normal fry within normal incubation period.

FIGURE 12-5. Three responses of fertilized English sole eggs to various concentrations of sulfite waste liquor.

Ultimate damage was exhibited by the mortality of fertilized eggs prior to any embryonic development. This is shown in Figure 12-5A by the relationship between the percentage of dead eggs and the concentration of sulfite waste liquor. Note the extremely low mortality rate (less than 3%) of eggs reared in the absence of SWL in the controls. This low value gives added significance to what may at first appear to be small losses in the lower and intermediate concentrations of SWL.

Another type of damage was manifested as failure of fertilized eggs to hatch in a normal period of time (Figure 12-5B). This category includes those dead eggs mentioned above and those eggs which exhibited some embryonic development but failed to hatch in the time period sufficient for the successful hatching of most (about 94%) control eggs. This damage, then, comprises both the mortality and the retarded development of fertilized eggs. Notice that a significant degree of hatching failure occurred at the intermediate concentrations of SWL (10 to 180 ppm SWL), and that severe damage of this type occurred at the higher waste concentrations (above 180 ppm SWL).

A third type of damage (Figure 12-5C) is evidenced by the failure of fertilized eggs to develop into normal appearing larvae. This is the broadest category of damage considered, for it includes all observed deviates: (1) dead eggs; (2) developing but unhatched eggs, and transitional larvae which had not reached, during the incubation period, the stage of development exhibited by larvae in the controls; and (3) developed but abnormal larvae. Although the percentage of abnormal and undeveloped larvae in the controls was quite high (about 29%), there was a significantly greater number of such aberrancies in all SWL concentrations above 13.5 ppm. In the intermediate SWL concentrations (13.5 to 180 ppm), about one-half of the eggs did not develop into normal larvae; at higher concentrations, very few eggs reached the normal larval stage.

In the latter two types of damage, portions of the anomalies noted were unhatched eggs and transitional larvae, each of which is evidence of retarded development as compared to the degree of development reached in the control solutions. These responses of retardation are more clearly illustrated in Figure 12-6. For each test solution and the control, the percentages of eggs which were left in each of the two pre-larval stages of development are shown. Note that significant retardation does not occur until SWL concentrations exceed 180 ppm. At higher concentrations, inhibition of development increases rapidly and is significant. Also, the results at the higher concentration indicates a change in the relative severity of inhibition. In SWL concentrations of 420 ppm and less, the percentages of developing eggs and transitional larvae are about equal. At 1,000 ppm, however, the percentage of developing eggs greatly exceeds that of transitional larvae. This indicates increased severity of inhibition; for obviously, the unhatched egg is in a state of further retardation than is the transitional larva.

DISCUSSION

The findings of the distribution study demonstrate that large numbers of English sole eggs are spawned into areas polluted by SWL

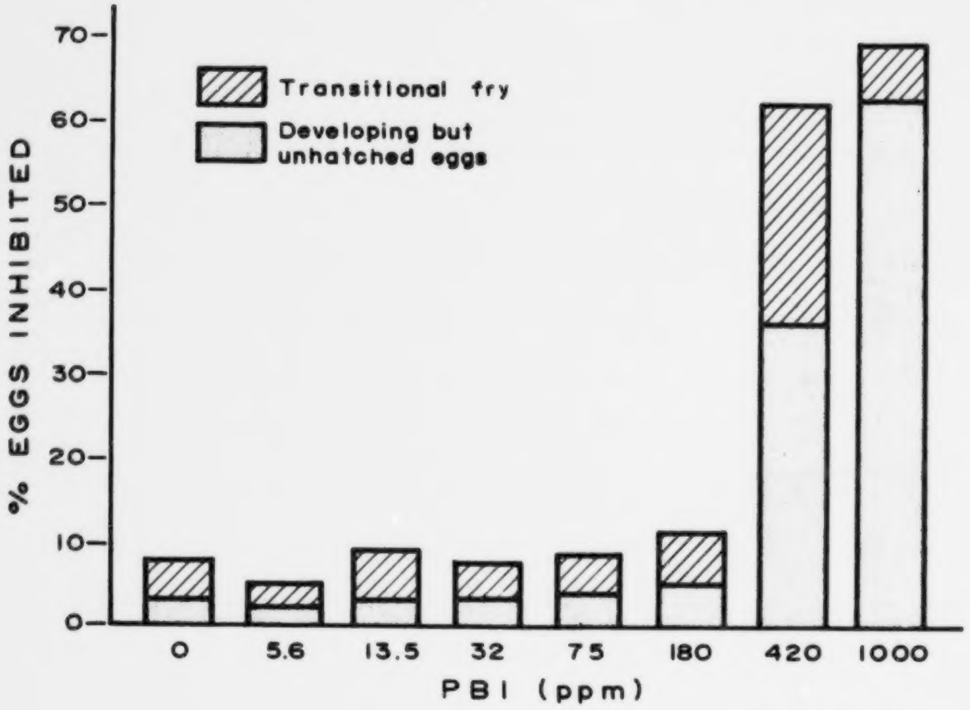


FIGURE 12-6. Percentages of English sole eggs in pre-larval stages of development at the end of incubation.

and that they develop in the surface layers where the highest concentrations of SWL occur. Hence, the critical tolerance levels determined by bioassay procedures are germane to situations existing in nature and should be used as tolerance limits of SWL concentration if the English sole population is not to be damaged.

The results of the bioassay study demonstrate that there is little doubt that sulfite waste liquor is an effective agent in disrupting the normal metabolic processes of developing English sole eggs. Figures 12-5A, B, and C show that deleterious effects occur at concentrations of SWL chronically present in surface waters of Bellingham Bay. Significant changes in response are rarely seen at waste concentrations of 6 ppm SWL but always at 14 ppm, suggesting strongly that a critical threshold exists somewhere around 10 ppm SWL. The damage induced at this threshold is not significantly increased by augmented concentrations of SWL until another critical level is reached at approximately 180 ppm SWL. Above this concentration, survival of exposed eggs is hopeless. Table 12-2 presents the results in terms of the percent increase in damage (above that observed in the controls) associated with the various tested concentrations of SWL. Note that even at 14 ppm there is a fivefold increase in egg mortality; the number of eggs that fail to hatch is three times the control level; and the percentage of eggs which fail to become normal larvae is almost double its very high control value. Evident are the plateau of damage at intermediate values of SWL, and a sharp increase in damage at SWL values above 180 ppm.

TABLE 12-2. Increase in response of English sole eggs to increasing concentrations of sulfite waste liquor.

SWL (ppm)	Dead Eggs (%)	Fail to Hatch (%)	Fail to Become Normal Larvae (%)
6	14	15	29
14	509	215	65
32	659	288	73
75	805	358	78
180	836	369	126
420	709	931	228
1,000	1,150	1,631	239

To afford optimal conditions for English sole egg development in Bellingham and Samish Bays, SWL concentrations in the surface waters should be limited to less than 14 ppm.

13. PLANKTON

The term "plankton" is applied to all those animals and plants which live freely in the water and which, because of their small size or feeble powers of locomotion, are passively drifted by the currents. Practically every major group of animals, either as adults, as larvae, or as both, is found among the plankton. Though the size range of the various planktonic organisms ranges from less than 5 microns (the smallest flagellates) to 2 meters (certain jellyfish), the vast majority are less than several millimeters long. Individually insignificant, collectively they are the most important group of organisms in the sea for they represent over 90% of the total biomass present.

Plankton form the base of the food web in the nutritional economy of the sea. Not only do they provide food for most small fish and invertebrates which in turn are the food of the larger fish, but they are also ingested directly by all filter feeders, such as oysters and clams, and some carnivores, such as juvenile salmon, herring, and many other commercially valuable shellfish and finfish. It is evident, then, that any factors which influence the plankton, secondarily influence the entire marine biota. It is for these cogent considerations that the Project conducted a study to evaluate the influence of pulp and paper mill wastes on the plankton.

Preceding page blank

STUDY

The objectives of the plankton study in the Bellingham area were (1) to determine the constituents, characteristics, and patterns of zooplankton and phytoplankton of the area; (2) to determine rates of phytoplankton productivity throughout the area; and (3) to relate these data to each other, to specified environmental factors such as light, nutrients, and SWL concentration, and to location with respect to the Georgia-Pacific mill. The results supply information about the capacity of the waters of Bellingham Bay to support life, and they show, to the extent possible, how mill wastes affect this capacity.

Ten sampling cruises were made at four- to eight-week intervals between August 1964 and July 1965, inclusive. On each cruise, ten stations (Figure 13-1) were occupied: four stations on a transect from Whatcom Waterway to the entrance of Hale Passage and one station at each of six oyster-raft sites. All work was conducted aboard the R/V HAROLD W. STREETER.

METHODS

At each station on each cruise, observations were made of the time of day, phase of tide, wind direction and velocity, weather and sea conditions, air temperature, light penetration (Secchi disc measurement), and total depth (sonic measurement). Water temperatures and salinities at surface, 7 feet, and 20 feet were measured with an induction salinometer (Industrial Instruments, Model RS-5). Solar energy at the surface was measured with a pyrheliometer. Relative light

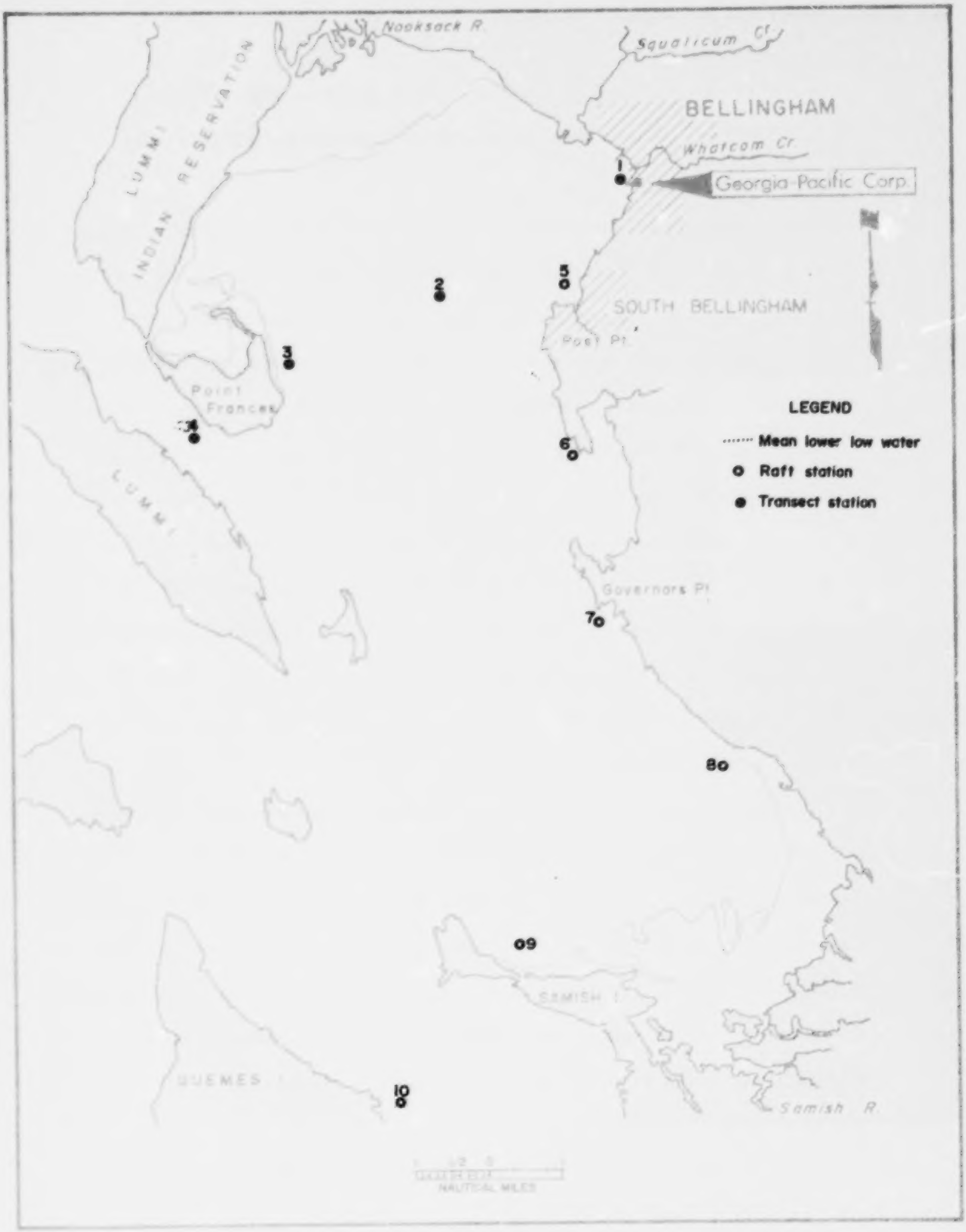

Nooksack R.
Squalicum Cr.
BELLINGHAM
Whatcom Cr.
Georgia-Pacific Corp.
LUMMI INDIAN RESERVATION
SOUTH BELLINGHAM
Post Pt.
Point Frances
LUMMI I.
Governors Pt.
SAMISH I.
GUEMES I.
Samish R.
1
2
3
4
5
6
7
8
9
10
LEGEND
Mean lower low water
Raft station
Transect station
NAUTICAL MILES

FIGURE 13-1. Phytoplankton productivity stations in the Bellingham area.

at depth (7 and 20 feet) was measured with an irradiance meter of Project design. Values were expressed as percentages of incidence surface light.

Zooplankton for quantitative analysis was collected in horizontal tows at surface and 20 feet at each station. Clark-Bumpus nets were employed. Net mesh was #6; thus, only those organisms exceeding 0.0165 inches in size were retained. The zooplankton collected were preserved in formalin and forwarded for identification and enumeration to taxonomists at Oregon State University Department of Oceanography. Table 13-1 is a faunal list of animals found and indicates those which were classified into species and those which were assigned to higher groupings. This information was computer processed and tabulated into the several categories: settled volume of organisms per unit volume of water, total numbers of organisms per unit volume of water, numbers of each form per unit volume of water, and the relative importance of each form in each sample.

Samples of water and phytoplankton were collected with a 6-liter, Scott-Van Dorn bottle at the surface and at the 7- and 20-foot depths, depths at which light levels were most frequently 35% and 2%, respectively, of surface illumination. These were collected for chemical analyses, phytoplankton identification, and the determination of primary productivity. Each sample was subdivided into nine subsamples, each of which was drawn directly from the sampler. These subsamples were analyzed as follows:

pH. A 50-ml aliquant was analyzed on board ship with a Beckman pH meter, Model GS.

TABLE 13-1. Faunal list of the zooplankton.

Copepoda

Acartia clausi
Acartia danae
Acartia longiremus
Acartia tonsa
Aetideus armatus
Aetideopsis rostrata
Calanus cristatus
Calanus finmarchicus
Calanus plumchrus
Candacia columbiae
Centropages mcmurrichi
Clausocalanus arcuicornis
Corycaeus affinis
Epilabidocera amphitrites
Eucalanus bungii
Eurytemora sp.
Harpacticoida
Metridia lucens
Microcalanus pusillus
Oithona similis
Oithona spinirostris
Oncaea sp.
Paracalanus parvus
Pareuchaeta japonica
Pseudocalanus minutus
Scolecithricella minor
Tortanus discaudatus
Copepodites
Nauplius larvae

Others

Appendicularia (Tunicata)
Chaetognatha (arrow worm)
Ctenophora
Doliolida (tunicata)
Euphausiacea
Evadne sp. (cladocera)
Gammaridae (Amphipoda)
Hyperiidae (Amphipoda)
Isopoda
Mysidacea
Natantia (shrimp)
Noctiluca sp. (Dinoflagellata)
Ostracoda
Podon sp. (Cladocera)
Salpa sp. (tunicata)
Siphonophora (jelly fish)
Medusae (jelly fish)

Pre-adult forms (other than Copepoda)

Anomura megalops (crab)
Anomura zoea (crab)
Amphipoda larva
Brachyura megalops (crab)
Brachyura zoea (crab)
Callianassa sp. larva (ghost shrimp)
Cirripedia cypris (barnacle)
Cirripedia nauplius (barnacle)
Cyphonautes larva
Euphausiacea calytopsis
Euphausiacea furcilla
Fish egg
Fish larva
Gastropoda larva
Mitraria larva
Mysidacea larva
Pelecypoda larva
Pluteus larva
Polychaeta larva
Natantia larva (shrimp)
Upogebia sp. larva (ghost shrimp)

DO. A 250-ml aliquant was immediately analyzed on board ship by the Alsterberg modification of Winkler method (A.P.H.A., 1962).

Salinity and SWL. A 250-ml aliquant was submitted to the laboratory for the determinations of salinity by titration (Strickland and Parsons, 1960) or with a Hytech inductive salinometer, Model RS-7A; and SWL by the modified Pearl-Benson method (Barnes, *et al.*; 1963).

Phosphate, Silicate, and Nitrate. Three 120-ml aliquants were immediately frozen and delivered frozen to the laboratory for the determination of reactive phosphate, reactive silicate, and nitrate by methods described by Strickland and Parsons (1960).

Reducing Sugars. A 120-ml aliquant was immediately frozen and delivered to the laboratory for the determination of reducing sugars by the Nelson method (Nelson, 1944) as modified for estuarine waters by W. O. Winkler (Project staff).

Phytoplankton. A 500-ml aliquant was preserved with formalin and transferred to the laboratory where it was concentrated, stained, and mounted on a microscope slide for identification and enumeration. Diatoms, certain of the other algae, and certain flagellates were identified to genus; other forms were grouped more broadly. Table 13-2 is a list of the forms found and indicates the level of identification pursued. All data were computer processed and tabulated in much the same way as the zooplankton data, and the same categories of information were extracted.

TABLE 13-2. Floral list of the phytoplankton and associated protozoa.

Chrysophyta

Centrales

Actinoptychus
Arachnoidiscus
Attheya
Bacteriastrum
Biddulphia
Cerataulina
Chaetoceros
Climacodium
Corethron
Coscinodiscus
Coscinosira
Cyclotella
Dactyliosolen
Ditylum
Eucampia
Euodia
Hemidiscus
Hyalodiscus
Isthmia
Lauderia
Leptocylindrus
Melosira
Paralia
Planktoniella
Rhizosolenia
Schroderella
Skeletonema
Stephanodiscus
Stephanopyxis
Streptotheca
Thalassiosira
Triceratium

Cyanophyta

Anabaena
Anacystis
Oscillatoria

Chlorophyta

Chlorella
Oocystis
Scenedesmus

Chrysophyta

Pennales

Achnanthes
Amphora
Amphipleura
Amphiprora
Asterionella
Campylodiscus
Campylosira
Ceratoneus
Climacosphenia
Cocconeis
Cymbella
Diatoma
Diploneis
Eunotia
Fragilaria
Gomphonema
Grammatophora
Gyrosigma
Licmophora
Navicula
Nitzschia
Plagiogramma
Pleurosigma
Rhabdonema
Rhoicosphenia
Rhopolodia
Stauroneis
Suriella
Synedra
Tabellaria
Thalasionema
Thalassiothrix
Tropidoneis

Protozoa

Ciliata

Amoeba
Salpingacantha
Tintinnopsis
Tintinnidium
Vorticella

Mastigophora

Euglena
Phacus

Dinoflagellata

Ceratium
Distephanus
Glenodinium

Chlorophyll. Phytoplankton chlorophyll content was used as a proportional measure of living plant material in a sample. A one-liter aliquant was coarse-filtered through #6-mesh plankton netting, and then drawn through an AA (0.8 micron aperture) Millipore filter. This procedure effectively excluded the large zooplankters but retained the phytoplankters on the membrane. After filtration the membrane was placed on filter paper, labeled, and stored in an aluminum dessicator in the freezer. Later, it was delivered to the laboratory for chlorophyll analysis by the modified method of Richards as described by Strickland and Parsons (1960). Measurements were made of chlorophyll a, b, c; plant carotenoids; and animal carotenoids. These data were computer-processed at the Department of Oceanography, Oregon State University.

Phytoplankton Productivity Rate. The rate of phytoplankton productivity was measured by following changes in the dissolved oxygen content of a water sample using the "Light and Dark Bottle" technique. Changes in dissolved oxygen were related to carbon production, using relationships established for the marine environment (Strickland, 1960), and results are expressed as the amount of carbon fixed per unit volume of water per unit time.

A two-liter aliquant was coarse-filtered through #6-mesh plankton netting and passed into a four-liter, opaque polyethylene bottle. The sample was allowed to warm slightly and then was shaken to reduce its dissolved oxygen content. After equilibration at the higher temperature, the sample was subdivided into three portions: the first portion was immediately analyzed to yield the basal oxygen value; the second portion was drawn into duplicate opaque bottles and incubated for six hours in the dark at ambient seawater temperature; the third portion was placed in duplicate clear bottles and incubated for six hours at ambient seawater temperature and under light conditions approximating those at which the water sample was taken. Both light and dark bottles were incubated in a two-compartment, shipboard incubator of Project design. Circulating seawater provided the same incubation temperature for both types of bottles. After incubation, the dissolved oxygen content of the second and third portions was determined, and the changes from the initial value were noted. Results were computer-processed at the Department of Oceanography, Oregon State University, and the productivity of each sample depth of each station was expressed as milligrams of carbon fixed per cubic meter of water per hour. All dissolved oxygen measurements were made by the Alsterberg modification of the Winkler method (A.P.H.A., 1962).

RESULTS

Data obtained from the study are summarized as mean values in Tables 13-3, 13-4, and 13-5. Note that almost all of the chemical and physical properties measured at a given depth show little significant variation among stations. The exceptions are the mean

TABLE 13-3. Mean values of properties measured at the surface in the Bellingham area; plankton study of August 1964 - July 1965.

Property	Station 1	2	3	4	5	6	7	8	9	10
Temperature (°C)	10.6	9.8	9.5	9.3	10.0	10.3	10.1	10.3	9.8	9.3
Secchi Disc (m)	2.0	4.3	3.4	4.2	3.4	4.5	3.9	3.8	4.0	4.8
Salinity (°/oo)	25.7	26.9	26.6	29.1	26.5	28.2	28.8	28.0	28.8	29.1
pH	7.6	8.0	7.9	7.9	7.7	7.9	8.0	8.0	8.0	7.9
Dissolved Oxygen (mg/l)	7.2	8.9	9.0	8.4	7.8	9.5	9.0	9.6	9.1	8.3
Dissolved Oxygen (% Sat)	74	91	91	86	80	[illegible]	95	101	96	86
Oxygen Consumption Rate (mgO$_2$/m^3/hr x 10^3)	93.8	13.3	14.0	7.4	26.0	18.2	10.5	13.5	11.7	13.7
NO$_3$ (microgram atoms/l)	6.5	10.2	9.7	17.4	10.0	13.7	15.2	13.1	16.7	19.1
PO$_4$ (microgram atoms/l)	0.9	1.1	1.0	1.5	1.1	1.2	1.5	1.4	1.6	1.8
SiO$_4$ (microgram atoms/l)	36.2	30.8	43.1	39.7	36.7	28.9	32.6	33.9	35.3	39.3
Sugar (mg/l)	2.1	0.6	0.3	0.4	0.1	0.6	0.2	0.1	0.6	0.4
SWL (ppm, 10% Solid Sol.)	336	56	38	16	85	[illegible]	5	7	8	6
Zooplankton Concentration (organisms/m^3)	6,518	2,365	2,474	2,113	4,203	4,079	6,436	5,673	2,579	1,436
No. of Taxa - Zooplankton	10.2	11.9	11.7	13.2	10.9	14.0	12.9	11.3	12.8	13.3
% Adults - Zooplankton	61	76	72	75	75	81	67	58	73	85
Dominant Forms - Zooplankton (in rank order)	Acartia clausi Barnacle nauplius * Pseudocalanus minutus Corycaeus affinis Cladocera-Podon sp.	Acartia clausi * Acartia longiremis Appendicularia Cladocera-Podon sp. Medusae	Acartia longiremis Medusae Appendicularia Acartia clausi Pseudocalanus minutus	Appendicularia Acartia longiremis Pseudocalanus minutus Noctiluca Corycaeus affinis	Barnacle nauplius Pseudocalanus minutus Appendicularia Acartia clausi * Noctiluca Acartia longiremis	Acartia clausi Barnacle nauplius Medusae * Acartia longiremis Corycaeus affinis	Acartia clausi Acartia longiremis Medusae Appendicularia Cladocera-Podon sp.	Medusae Acartia clausi Acartia longiremis Polychaeta Larva Barnacle nauplius	Appendicularia Corycaeus affinis Acartia longiremis Medusae Noctiluca	Acartia longiremis Appendicularia Acartia clausi Noctiluca Corycaeus affinis
Chlorophyll a (mg/m^3)	17.0	21.8	20.2	22.7	20.1	37.2	26.8	28.8	58.3	25.3
Phytoplankton Concentration (cells/l x 10^{-3})	241	236	231	208	93	249	366	396	394	196
No. of Taxa - Phytoplankton	4.9	4.4	4.8	5.1	3.0	5.8	5.2	5.9	5.6	6.3
Dominant Forms - Phytoplankton (in rank order)	Anacystis Chaetoceros Thalassiosira Melosira Cyclotella	Chaetoceros Skeletonema Anacystis Coscinodiscus - -	Thalassiosira Chaetoceros Anacystis Navicula Cyclotella	Skeletonema Chaetoceros Thalassiosira Melosira Anacystis	Skeletonema Thalassiosira Chaetoceros Navicula Anacystis	Thalassiosira Chaetoceros Skeletonema Anacystis Melosira	Thalassiosira Skeletonema Chaetoceros Anacystis Cocconeis	Thalassiosira Anacystis Navicula * Chaetoceros Skeletonema	Skeletonema Coscinodiscus Cocconeis Thalassiosira Navicula	Chaetoceros Skeletonema Anacystis Coscinodiscus Thalassiosira
Phytoplankton Productivity Rate (mgC/m^3/hr)	4.6	25.2	24.9	24.3	13.1	21.4	23.3	21.8	40.9	16.7

* Equal Rank

TABLE 13-4. Mean values of properties measured at 7 feet in the Bellingham area, plankton study of August 1964 - July 1965.

Property	Station									
	1	2	3	4	5	6	7	8	9	10
Temperature (°C)	9.8	9.3	9.5	9.1	9.4	9.7	9.7	9.6	9.3	8.9
Light Remaining (°/o of surface)	10.8	22.6	19.6	28.1	20.6	27.3	28.4	29.1	31.3	35.3
Salinity (°/oo)	27.2	28.0	26.8	28.5	28.0	28.6	28.9	28.6	29.0	29.3
pH	7.8	7.9	7.9	7.9	7.8	8.0	8.0	8.0	8.0	7.9
Dissolved Oxygen (mg/l)	8.0	8.8	9.2	8.3	7.8	9.4	8.8	9.2	8.7	8.0
Dissolved Oxygen (°/o Sat)	81	91	93	85	80	97	91	95	89	82
Oxygen Consumption Rate (mgO$_2$/m^3/hr x 10^3)	53.4	9.7	9.7	6.6	11.2	7.1	5.6	8.8	11.2	13.7
NO$_3$ (microgram atoms/l)	9.8	11.2	11.9	17.6	12.1	16.7	16.3	15.1	18.2	21.6
PO$_4$ (microgram atoms/l)	1.0	1.2	1.2	1.6	1.2	1.5	1.6	1.6	1.8	1.9
SiO$_4$ (microgram atoms/l)	33.0	28.2	12.9	39.0	32.4	31.3	35.9	34.2	18.2	41.2
Sugar (mg/l)	0.9	0.4	0.3	0.4	0.2	0.4	0.5	0.5	0.4	0.1
SWL (ppm, 10% Solid Sol.)	120	38	36	12	43	9	6	6	8	6
Chlorophyll a (mg/m^3)	14.5	22.9	17.1	18.7	15.7	29.0	23.2	24.6	40.2	20.2
Phytoplankton Concentration (cells/l x 10^{-3})	222	159	146	263	203	217	195	148	593	197
No. of Taxa - Phytoplankton	4.5	4.1	4.1	4.2	3.6	6.1	5.4	6.7	5.8	6.7
Dominant Forms - Phytoplankton (in rank order)	Thalassiosira Anacystis Chaetoceros * Cyclotella Melosira	Thalassiosira Anacystis Chaetoceros Skeletonema - -	Thalassiosira Skeletonema Chaetoceros * Anacystis Navicula	Thalassiosira Chaetoceros Anacystis Skeletonema - -	Skeletonema Anacystis Thalassiosira Chaetoceros Cyclotella	Anacystis Skeletonema Thalassiosira Chaetoceros Melosira	Skeletonema * Thalassiosira Melosira * Chaetoceros Anacystis	Thalassiosira Chaetoceros * Skeletonema Anacystis Cocconeis	Thalassiosira Skeletonema Coscinodiscus Anacystis Chaetoceros	Skeletonema Synedra Coscinodiscus Thalassiosira Anacystis
Phytoplankton Productivity Rate (mgC/m^3/hr)	0.9	3.6	2.7	5.5	1.9	4.3	5.3	5.9	8.9	3.1

* Equal Rank

TABLE 13-5. Mean values of properties measured at 20 feet in the Bellingham area, plankton study of August 1964 - July 1965.

Property	Station 1	2	3	4	5	6	7	8	9	10
Temperature (°C)	9.5	9.3	9.5	9.2	9.2	9.5	9.7	9.3	9.3	9.0
Light Remaining (°/o of surface)	1.8	5.1	6.2	5.8	3.6	6.2	6.6	5.0	6.4	8.7
Salinity (°/oo)	28.9	29.0	27.9	28.9	29.0	29.1	29.2	29.1	29.1	29.4
pH	7.8	7.9	7.9	8.0	7.9	8.0	7.9	8.0	8.0	7.9
Dissolved Oxygen (mg/l)	7.7	8.6	8.3	8.1	7.6	8.5	8.3	8.3	8.6	8.1
Dissolved Oxygen (°/o Sat)	79	89	85	83	78	88	86	86	89	83
Oxygen Consumption Rate ($mgO_2/m^3/hr \times 10^3$)	6.2	10.3	5.6	3.6	-1.3	8.6	4.8	6.6	11.9	7.0
NO_3 (microgram-atoms/l)	13.8	14.9	13.4	18.2	17.1	17.5	15.9	16.7	18.4	18.0
PO_4 (microgram-atoms/l)	1.6	1.6	1.4	1.8	1.8	1.6	1.7	1.7	1.7	1.6
SiO_4 (microgram-atoms/l)	36.5	33.1	31.9	38.4	37.3	35.2	35.8	36.3	38.6	40.0
Sugar (mg/l)	0.5	0.2	0.4	0.4	0.3	0.1	0.1	0.9	0.1	0.7
SWL (ppm, 10°/o Solid Sol.)	22	11	18	8	13	6	4	5	6	5
Zooplankton Concentration (organisms/m^3)	5,221	5,056	8,515	3,401	6,131	6,338	9,723	4,796	5,815	5,218
No. of Taxa - Zooplankton	15.7	14.6	16.0	17.4	15.1	14.6	15.1	14.5	13.9	14.2
% Adults - Zooplankton	61	61	61	58	67	58	74	57	65	64
Dominant Forms - Zooplankton (in rank order)	Appendicularia Pseudocalanus minutus * {Acartia clausi Medusae Acartia longiremis}	Appendicularia Pseudocalanus minutus Barnacle nauplius Acartia clausi Medusae	Appendicularia Noctiluca Pseudocalanus minutus Fish Eggs * {Corycaeus affinis Medusae}	Appendicularia Pseudocalanus minutus Acartia clausi Noctiluca Medusae	Appendicularia Acartia clausi Pseudocalanus minutus Medusae Noctiluca	Appendicularia Acartia clausi Pseudocalanus minutus Barnacle nauplius Acartia longiremis	Brachyuran Crab Zoea Pseudocalanus minutus * {Appendicularia Noctiluca} Acartia clausi	Pseudocalanus minutus Acartia clausi Appendicularia Medusae Brachyuran Crab Zoea	Appendicularia Pseudocalanus minutus Noctiluca Barnacle nauplius Medusae	Appendicularia Pseudocalanus minutus Corycaeus affinis * {Fish Eggs Barnacle nauplius}
Chlorophyll a (mg/m^3)	23.3	27.1	26.8	23.0	23.6	33.9	27.9	31.2	31.2	21.7
Phytoplankton Concentration (cells/l $\times 10^{-}$)	260	242	341	201	131	306	465	155	332	214
No. of Taxa - Phytoplankton	4.6	5.4	4.3	5.5	4.2	5.3	7.5	5.4	6.4	5.6
Dominant Forms - Phytoplankton (in rank order)	Skeletonema Chaetoceros Thalassiosira Cyclotella - -	Thalassiosira Anacystis Chaetoceros Skeletonema - -	Thalassiosira Chaetoceros Melosira Anacystis Skeletonema	Thalassiosira Chaetoceros Coscinodiscus Skeletonema Melosira	Skeletonema Chaetoceros Thalassiosira Coscinodiscus Anacystis	Thalassiosira Skeletonema Coscinodiscus * {Chaetoceros Melosira}	Skeletonema Thalassiosira Melosira * {Anacystis Cocconeis}	* {Chaetoceros Thalassiosira} Anacystis Cocconeis Melosira	Chaetoceros Cocconeis Thalassiosira Anacystis * {Skeletonema Coscinodiscus}	Chaetoceros Thalassiosira Skeletonema Coscinodiscus Melosira
Phytoplankton Productivity Rate (mgC/m^3/hr)	1.4	4.8	3.1	.4	1.3	..0	2.5	1.8	2.6	3.5

* Equal Rank

SWL concentrations which decrease with distance from the Georgia-Pacific mill and the very high mean sugar concentration and mean oxygen consumption rate near the mill (Station 1). These data describe findings in keeping with those discussed in Section 7.

Examination of the biological data (Tables 13-3, 13-4, and 13-5) indicates that there is little variation in the dynamic structure of the plankton community among the various stations at a given depth. There is no significant difference between the annual mean values at any one station and the annual mean values at all other stations combined for the following: chlorophyll a concentration, phytoplankton concentration, number of phytoplankton taxa (diversity), zooplankton concentration, number of zooplankton taxa, and the percentage of adults making up the zooplankton. Further, the dominant organisms of both phytoplankton and zooplankton are generally the same at all stations. It is thus apparent that the structure of the plankton community is essentially the same throughout the study area, even though the raw data showed considerable, but expected, seasonal variation in the numbers and kinds of plankters.

Phytoplankton productivity rate is the only biological property that exhibited significant interstation differences in annual mean values. Note in Table 13-3 that low rates of productivity were obtained at surface at Station 1 (a mean of 4.6 mg carbon fixed/m^3/hr) and at Station 5 (a mean of 13.1 mg carbon fixed/m^3/hr). To evaluate the differences between these values and mean values obtained at other stations in the study area, consideration was given to information exhibited by all raw data--that conditions of low temperature and low light intensity (depth) also inhibit productivity. Accordingly, with the removal of all data collected at water temperatures less than 10°C and all data collected at the 7- and 20-foot depths, it was found that mean productivity at Station 1 was significantly lower (99% level) than the associated mean value at all other stations combined, and that mean productivity at Station 5 was significantly lower (95% level) than the associated mean value at all other stations combined except Station 1. Otherwise, no significant interstation differences in productivity were seen.

Because average SWL concentrations are highest at Stations 1 and 5, an association with productivity was suggested and the graph of Figure 13-2 was constructed using only those data collected at surface and at temperatures equal to or greater than 10°C. To compensate for the variation found in standing crop, the values in this graph are presented as productivity rate per unit of chlorophyll a. Note that a monotonic relationship does not exist between productivity rate/mg of chlorophyll a and SWL concentration, but that a threshold effect occurs. Phytoplankton productivity falls off markedly at SWL values around 50-70 ppm. This drop in productivity per unit of chlorophyll a is shown in a different manner in Table 13-6, where the productivity data of Figure 13-2 is summarized by groupings associated with the SWL concentration ranges of 0-50 ppm, 51-100 ppm, and 101 ppm and greater.

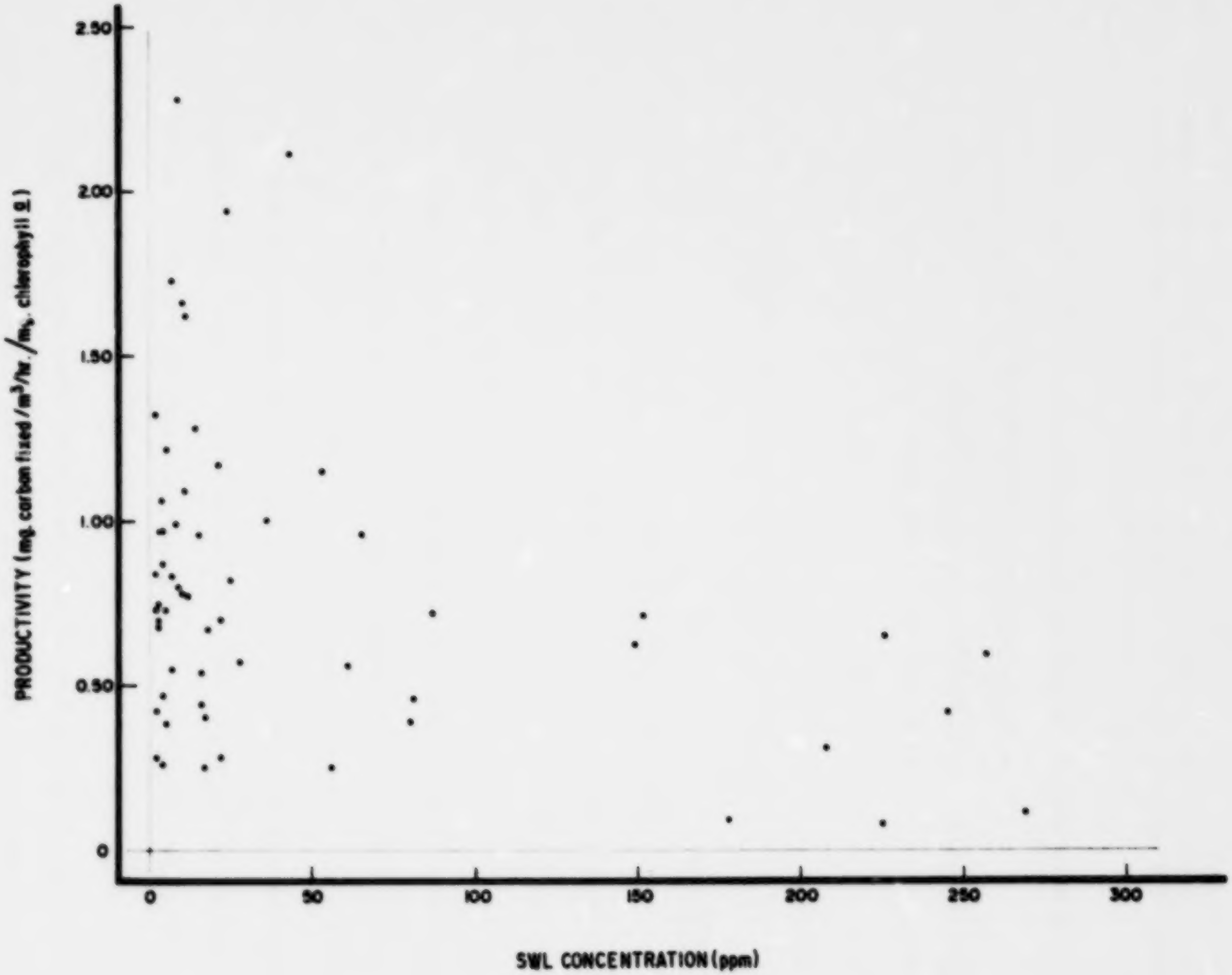


FIGURE 13-2. The relationship of phytoplankton productivity rate per mg of chlorophyll a vs. SWL concentration for samples collected at the surface at temperatures equal to or greater than 10° in the Bellingham study area.

TABLE 13-6. Summary of phytoplankton productivity rate per unit of chlorophyll a (mg carbon fixed/m^3/hr/mg Chl.a) associated with the three broad ranges of SWL concentration observed in the Bellingham area; for samples taken at the surface at temperatures equal to or greater than 10°C.

Statistic	SWL Concentration Range 0-50 ppm	51-100 ppm	Greater than 100 ppm
Range	0.25 to 2.28	0.25 to 1.15	0.08 to 0.71
Mean	0.90	0.64	0.44
Median	0.80	0.56	0.51

DISCUSSION

It is shown that phytoplankton populations are essentially the same, qualitatively and quantitatively, at each of the stations examined in the Bellingham area. Phytoplankton productivity, also, varies little among stations throughout the study area except at Station 1 in Bellingham Harbor and Station 5 near Post Point. At these sites, the phytoplankton productivity rate commonly is quite low; hence the capacity of these waters to effectively support the lower organisms that serve as food for higher forms, such as salmon and oysters, is impaired. The conclusion drawn is that phytoplankton are continuously being swept throughout the study area by water currents and circulation, and, that once these cells are brought into contact with high concentrations of pulping wastes, they are physiologically injured and fail to function normally. This injury does not translate into alteration of the community structure because of the constant movement of phytoplankton into and out of the affected area.

The data presented in Figure 13-2 and Table 13-6 clearly show that the phytoplankton sustain significant injury at SWL concentrations greater than 50 ppm. Referring to Figure 7-7, it is seen that average SWL concentrations greater than 50 ppm prevail throughout the northeastern quarter of Bellingham Bay. Consequently, a substantially large portion of the Bellingham study area is affected by water quality inimical to phytoplankton.

14. PERIPHYTON

Free surfaces of submerged objects soon become coated with an aggregation of small plants and animals. This kind of aggregation is called "periphyton" and includes both benthic and facultative benthic-planktonic organisms. Truly planktonic forms which have no means of attachment are excluded unless they become enmeshed in the periphyton film.

PERIPHYTON STUDY

The periphyton communities in the Bellingham-Samish Bay system were studied to determine the effects of pulping wastes to this portion of the marine biota. Field work for the principal part of the study was done between February 9 and September 1, 1964. Subsequent samples were taken from November 17 to December 2, 1964 to evaluate changes in conditions concurrent with a shutdown of the Georgia-Pacific mill. Sample analyses have been completed, and the statistical evaluation of results is under way.

Methods. Glass slides, suitably mounted in a rack (Figure 14-1), were submerged 30 inches below the water surface at each of 17 stations (Figure 14-2). Two, one-by-three-inch slides were placed in each tier of grooves to provide upward and downward directed collecting surfaces. Racks were suspended from the adult oyster rafts at Stations 5, 6, 7, 8, 9, and 10. As a check on possible shadow effects from the rafts, additional racks were suspended from anchored floats approximately 50 feet

Preceding page blank

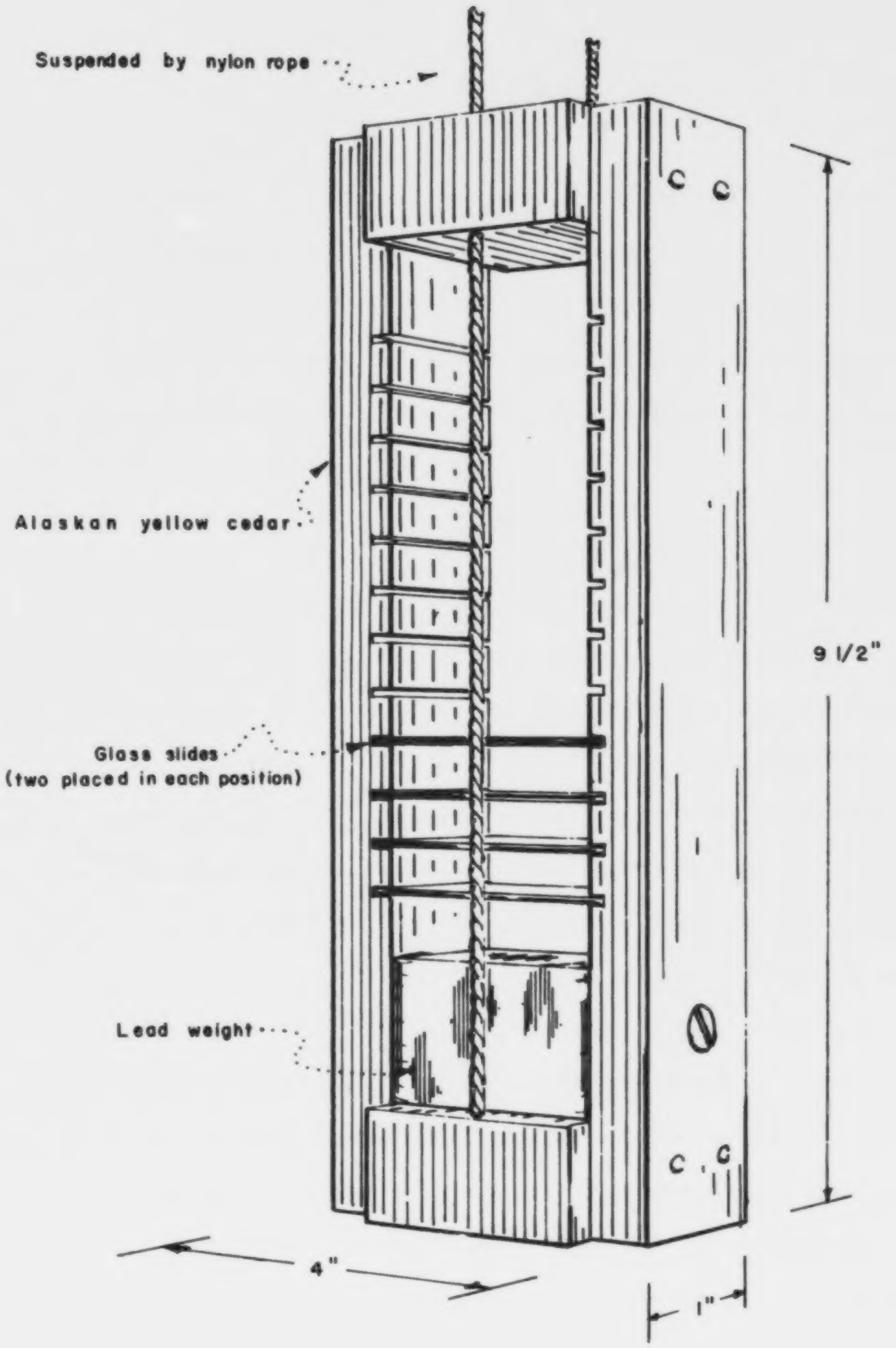

Suspended by nylon rope
Alaskan yellow cedar
Glass slides
(two placed in each position)
Lead weight
9 1/2"
4"
1"

FIGURE 14-1. Glass slide rack.

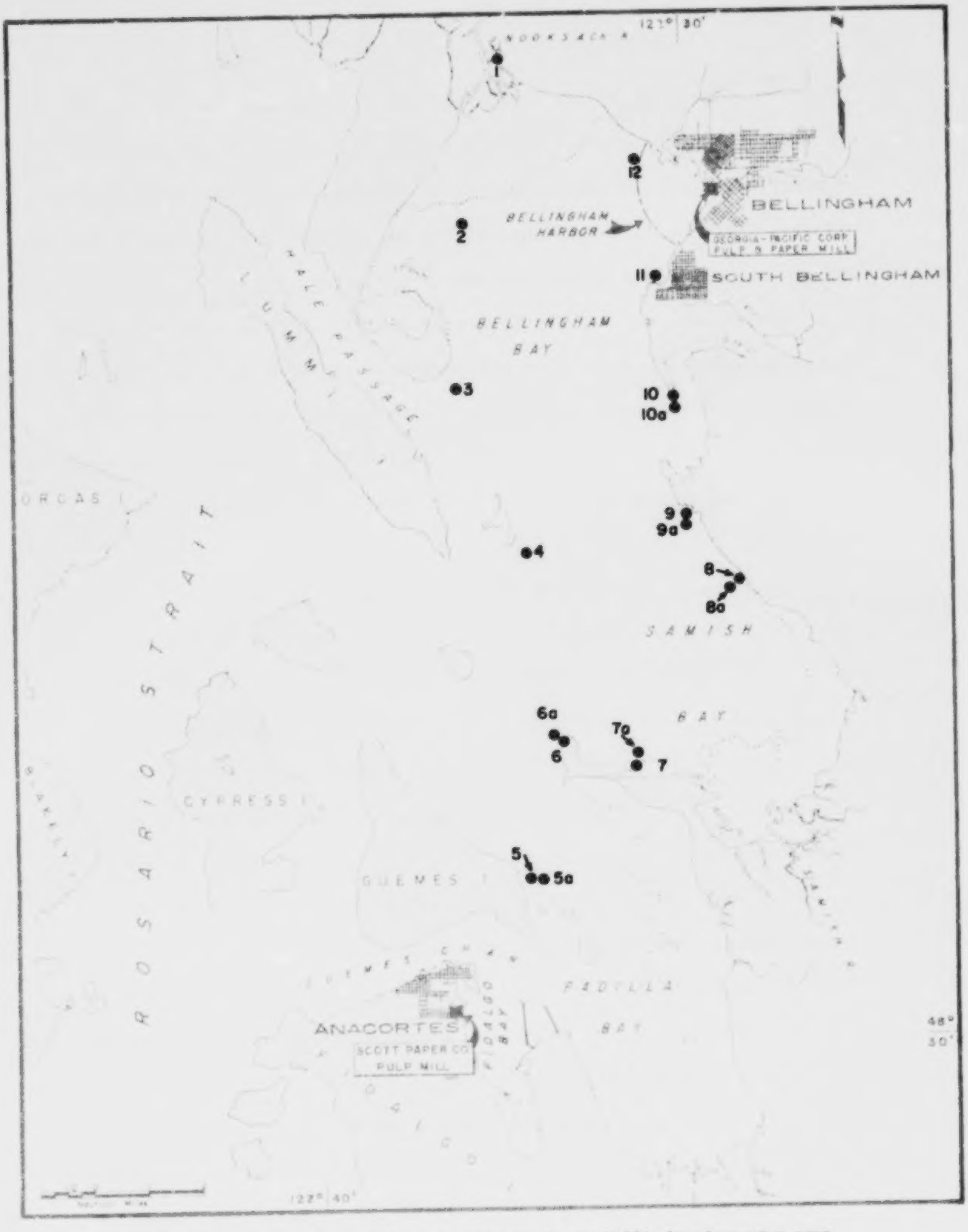

NOOKSACK R.
122° 30'
1
12
BELLINGHAM
BELLINGHAM HARBOR
GEORGIA-PACIFIC CORP. PULP & PAPER MILL
2
11
SOUTH BELLINGHAM
HALE PASSAGE
LUMMI I.
BELLINGHAM BAY
3
10
10a
ORCAS I.
9
9a
4
8
8a
SAMISH BAY
ROSARIO STRAIT
6a
6
7a
7
CYPRESS I.
BLAKELY I.
5
5a
GUEMES I.
GUEMES CHAN.
PADILLA BAY
ANACORTES
SCOTT PAPER CO. PULP MILL
FIDALGO BAY
SAMISH R.
48° 30'
122° 40'

FIGURE 14-2. Periphyton slide rack stations in the Bellingham-Anacortes area.

from the rafts. These auxiliary stations were labeled 5a, 6a, 7a, 8a, 9a, and 10a, respectively. At Stations 2, 3, 4, 11, and 12 (where no oyster rafts were located), racks were similarly suspended from anchored floats. Station 1, established at the Marietta Bridge over the Nooksack River, was abandoned before the end of the study.

Slides were exposed for intervals of 7 to 30 days. The collection schedule was designed so that the period of exposure for one slide overlapped that of another; *e.g.*, Slide 1 was exposed from day-one to day-seven, Slide 2 from day-one to day-fourteen, Slide 3 from day-seven to day-fourteen, and so on. A total of 1,174 slides was exposed during the study.

Exposed slides were removed from the racks and placed in a solution of 4% formalin and seawater. In the laboratory, these were scraped, and the attached organisms were stained and resuspended on counting slides. Identification and enumeration were accomplished by phase-microscopic examination of 20 fields at 400X magnification. Table 14-1 lists the genera identified. Results are expressed in total number of organisms per unit area and in number of organisms of each genus per unit area.

With each collection of slides, water samples were taken at the 3-foot depth. These were analyzed for:

1. salinity--by the silver nitrate titration method (Strickland and Parsons, 1960) or with a Hytech, Model RS-7A, induction salinometer;
2. PBI--by the method described by Barnes, *et al*. (1962);
3. total soluble phosphate--in freshwater samples by the stannous chloride method (A.P.H.A., 1962) and in saltwater samples by the method described by Strickland and Parsons (1960);

TABLE 14-1. List of periphytic taxa identified and enumerated.

Chrysophyta-Pennales (Diatoms)

- Achnanthes
- Amphora
- Asterionella
- Ceratoneis
- Climacosphenia
- Cocconeis
- Diatoma
- Eunotia
- Fragilaria
- Gomphonema
- Grammatophora
- Isthmia
- Lauderia
- Licmophora
- Meridian
- Navicula
- Nitzschia
- Pleurosigma
- Rhabdonema
- Rhoicosphenia
- Rhopolodia
- Stauransis
- Stauroneis
- Striatella
- Surirella
- Synedra
- Tabellaria
- Thalassiothrix
- Trepidomeis
- Tropidoneis

Chrysophyta - Centrales

- Actinoptychus
- Biddulphia
- Campylodiscus
- Chaetoceros
- Coscinodiscus
- Cyclotella
- Ditylum
- Hyalodiscus
- Melosira
- Paralia
- Planktoniella
- Rhizosolenia
- Skeletonema
- Thalassiosira

Chlorophyta (Green algae)

- Agmenellum
- Chlorella
- Desmid
- Rhizoclonium
- Ulothrix
- Volvox

Cyanophyta (Blue-green algae)

- Anabaena
- Anacystis
- Oscillatoria

Protozoa

- Suctoria
  - Ephelota
  - Tokophrya
- Mastigophera
  - Distephanus
- Sarcodina
  - Actinopodia
  - Amoeba
- Ciliata
  - Epistylis
  - Leprotintinnus
  - Salpingacantha
  - Tintinnidium
  - Tintinnopsis

Miscellaneous

- Amphipoda
- Bryozoa
- Cirripedia
- Copepoda
- Hydra
- Isopoda
- Nauplius larva
- Nematoda
- Obelia
- Pelecypoda
- Polychaeta

4. total soluble nitrate--in freshwater samples by the phenoldisulfonic acid method (A.P.H.A., 1962) and in saltwater samples by the method described by Strickland and Parsons (1960).

The statistical analysis of data was done by Dr. Gerald Paulik, Biometrician, University of Washington School of Fisheries. An analysis of the slides collected at the stations is summarized in Table 14-2.

TABLE 14-2. Numbers of genera of organisms on glass slides in twelve stations in Bellingham Bay.

Station	Number of Slides Examined	Total Number of Genera Found at Station
1	4	11
2	46	18
3	52	32
4	38	25
5	73	33
6	76	37
7	71	35
8	72	39
9	76	40
10	67	36
11	48	39
12	34	17

Inspection of the data presented in Table 14-2 reveals that reduced numbers of genera were found at Stations 1, 2, and 12. Station 1, located in the Nooksack River, reflects those predominantly freshwater forms not affected by mill wastes. Stations 2 and 12 were located in the extreme northern portion of Bellingham Bay and may reflect the influences of environmental factors other than pulping wastes.

These data are undergoing additional analyses through the use of very sophisticated computer programs.

15. BACTERIAL QUALITY

The waters of the Bellingham area, particularly those of Bellingham Harbor, are used for commercial fishing, towboat operations, recreational boating, log rafting and sorting activities, and shoreline recreation. Water contact incidental to these uses makes the bacterial quality of these waters important. Sources of bacterial pollution include discharges of primary treated wastes from the City of Bellingham and untreated wastes from the Fairhaven sewers (see Figure 5-1), sundry boats, and waterfront industries and properties. To evaluate this pollution problem, the Project conducted bacteriological studies in Bellingham Harbor and contiguous waters.

STUDIES

Five bacteriological surveys were conducted in the Bellingham area by the Project, one each in August 1964 and March, April, May, and June 1965. On each survey, surface samples were taken from each of seventeen stations (Figure 15-1) located to describe the bacterial quality of upper Bellingham Bay, the Nooksack River, and Whatcom Creek. Concentrations of total coliforms and fecal streptococci were determined for each sample. Surface water temperature and salinity also were measured at each station whenever possible.

METHODS

Bacteriological samples were collected in sterilized, 6-ounce capacity, wide-mouth polyethylene bottles. Samples were either

Preceding page blank

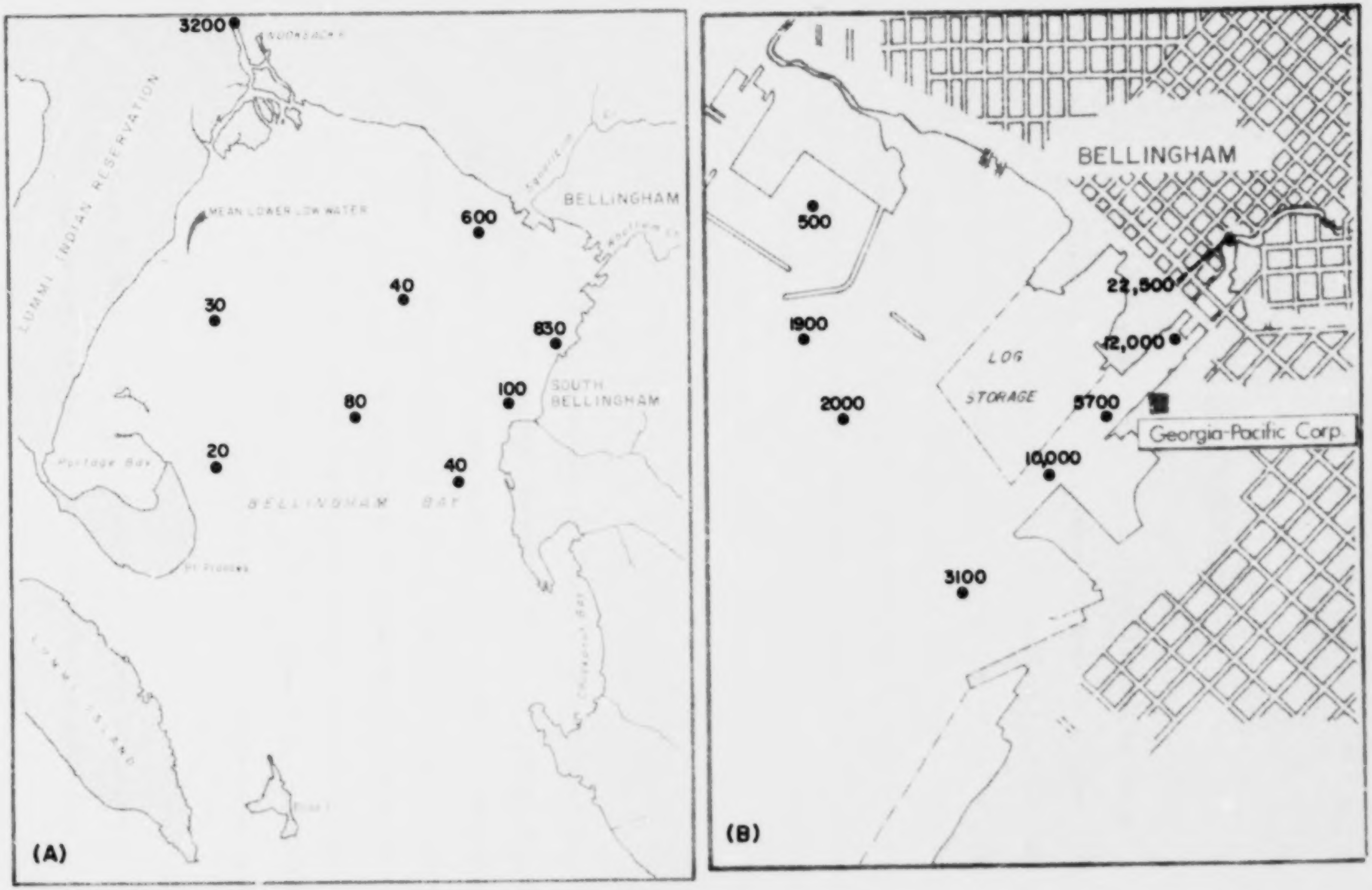

3200
LUMMI INDIAN RESERVATION
MEAN LOWER LOW WATER
BELLINGHAM
600
40
30
830
100
SOUTH BELLINGHAM
80
20
40
BELLINGHAM BAY
Portage Bay
LUMMI ISLAND
(A)
BELLINGHAM
500
22,500
1900
12,000
LOG STORAGE
2000
5700
Georgia-Pacific Corp.
10,000
3100
(B)

FIGURE 15-1. Bacteriological sampling stations and five-cruise average concentrations of total coliforms in (A) Bellingham Bay and (B) Bellingham Harbor; data from Project studies, 1964-1965.

processed for bacterial analysis immediately in the shipboard laboratory of the Project's oceanographic vessel HAROLD W. STREETER, or were refrigerated and transported directly to the Project's Portland, Oregon laboratory for processing. Under the latter method the maximum elapsed time between collection and laboratory processing did not exceed eight hours. All total coliforms and fecal streptococci determinations were performed using the membrane filter technique (A.P.H.A., 1965).

RESULTS

Study results are summarized in Figure 15-1 in terms of the average concentration of total coliforms observed at each station over the five surveys. Note that the average bacterial count exceeded 1,000 organisms/100 ml throughout most of Bellingham Harbor and at the Nooksack River and Whatcom Creek stations. Also note that bacterial concentrations increase significantly with proximity to Whatcom Waterway. Based on these results the most significant probable source of bacterial pollution is the effluent from the City of Bellingham's primary sewage treatment plant.

DISCUSSION

Bacterial standards presently proposed by the Washington Pollution Control Commission require that average concentrations of total coliforms be less than 1,000/100 ml for safe water-contact use of coastal waters. Results of Project studies show that this value is grossly exceeded in Bellingham Harbor, particularly in Whatcom Waterway. Therefore, these waters are polluted and, under present conditions, should not be used for water-contact activities.

The most significant probable source of bacterial pollution to the Harbor is the effluent from the City of Bellingham's primary waste treatment plant discharging to Whatcom Waterway. Untreated wastes from the Fairhaven sewers and from waterfront properties also contribute substantially to this problem. Further, high BOD's and settleable solids loadings associated with these wastes compound the water quality degradation in Bellingham Harbor resulting from waste discharge by the Georgia-Pacific pulp and paper mill complex.

16. SUMMARY

The Georgia-Pacific Corporation's pulp, board, and paper mill located on Whatcom Waterway at Bellingham is the principal source of wastes present in waters of the Bellingham study area. These wastes, discharged directly into Whatcom Waterway adjacent to the mill, are found dispersed in near-surface waters throughout the Bellingham-Samish Bay system and, on occasion, even in the Anacortes area.

Project studies have shown that waste levels present in the system are excessively damaging to the indigenous marine community. These damages are essentially of two specific types: (1) those of an acute nature, occurring mainly in Bellingham Harbor and associated with the concentrated sulfite waste liquors and settleable solids-bearing wastes discharged into Whatcom Waterway, and (2) those of a more chronic nature, occurring throughout the outer waters of the Bellingham-Samish Bay system and associated with dilute concentrations of sulfite waste liquors.

In Bellingham Harbor, waste discharge from the Georgia-Pacific mill results in high waste concentrations, sludge deposits, and attendant water quality degradation. These conditions are incompatible with marine life and interfere with other legitimate water uses. Specifically, the wastes have been shown to:

1. Be injurious to juvenile salmon, resulting in extensive damage to the salmon fishery while juveniles are migrating through the Harbor area.

2. Suppress phytoplankton activity within the Harbor.

3. Contain settleable waste solids that form sludge deposits in Bellingham Harbor; these deposits damage bottom organisms and produce harmful water quality degradation, as well as cause general aesthetically unattractive conditions.

It is imperative that all wastes discharged from the Georgia-Pacific pulp, board, and paper mill be treated for removal of settleable solids, and that the point of waste discharge be removed from the confines of Whatcom Waterway.

Of even greater importance to the marine communities of the study area are the concentrations of sulfite waste liquor found dispersed throughout the surface waters of Bellingham and Samish Bays. These wastes, even in relatively dilute concentrations (5 to 15 ppm SWL), are damaging to immature forms of indigenous fish and shellfish, with such damages generally decreasing with distance from the Georgia-Pacific mill complex. Specifically, Project studies have shown that such wastes:

1. Damage oyster larva throughout the study area, with excessive damage produced in northern Bellingham Bay.

2. Cause some adult and juvenile oyster mortality, particularly in Bellingham Bay, and, more importantly, adversely affect oyster growth and market condition throughout the study area.

3. Damage English sole eggs which are seasonally present in surface waters throughout the study area. Extensive damage would be expected at waste levels found in northern Bellingham Bay, with lesser damages expected in the remainder of the Bellingham-Samish Bay system.

English sole eggs and Pacific oyster larva are two forms studied intensively by the Project, but which represent a large group of marine organisms expected to be similarly affected by Georgia-Pacific wastes. This group includes some 10 species of sole, 6 species of cod, anchovy, herring, smelt, 3 species of clams, and crabs, to mention some of the more important.

The physical characteristics of the Bellingham-Samish Bay system severely limit its ability to assimilate waste products. To prevent additional damages to these important marine resources it is, therefore, necessary that sulfite waste liquors discharged by Georgia-Pacific mill be reduced significantly at the source. Minimum protection of these organisms during their most sensitive life stages requires that SWL concentrations in the surface 50 feet of depth not exceed 10 ppm beyond the initial waste dispersion zone. The initial waste dispersion zone is defined as that area of Bellingham Bay north of an east-west line (magnetic) extending from Post Point to Lummi Peninsula.

Discharge of raw and partially treated domestic wastes from the City of Bellingham results in bacterial concentrations in the Bellingham Harbor hazardous to human health.

Stokely-Van Camp and Bumble Bee Seafoods also discharge solids-bearing wastes into Bellingham Harbor which contribute to the formation of sludge deposits.

Part 3

ANACORTES STUDIES

Preceding page blank

17. INTRODUCTION

The Scott Paper Company sulfite pulp mill is the waste source of principal consideration in the Anacortes area. Located in the City of Anacortes, this mill discharges all process wastes into Guemes Channel (Figure 17-1).

Other major wastes sources in the area are the Texaco and Shell oil refineries on March Point, the City of Anacortes sewage treatment plant, the Sabastian Stuart Fish Co., and the Fishermen's Packing Corp. Figure 17-1 also shows the locations of these sources.

STUDY AREA

The Anacortes study area includes Padilla and Fidalgo Bays and Guemes Channel (Figure 17-2; also see Figure 5-2). The City of Anacortes is the only municipality in the area.

Both Padilla and Fidalgo Bays are shallow. Depths throughout all of Fidalgo Bay and most of Padilla Bay are less than 60 feet (see the 60-feet depths contour, Figure 17-2). The deeper waters of Padilla Bay occupy a channel along the east side of Guemes Island. This channel joins the Bellingham study area to the north, and it carries some exchange of waters between the two study areas.

Guemes Channel, a narrow, moderately deep channel, carries large tidal flows between Padilla-Fidalgo Bays and Rosario Strait. These flows and attending turbulence effect rapid transport and dispersion of wastes discharged into the Channel.

Preceding page blank

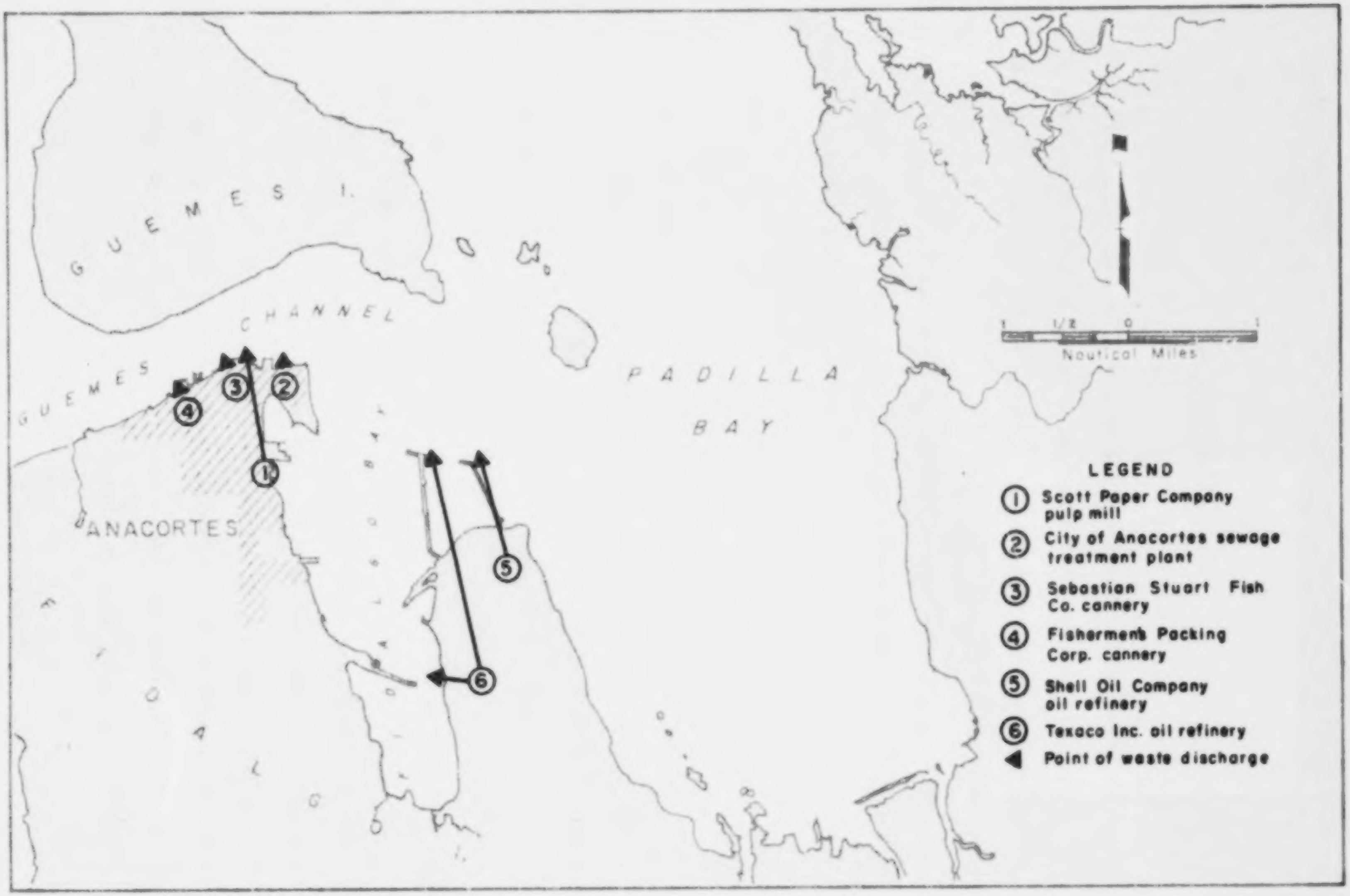

GUEMES I.
GUEMES CHANNEL
PADILLA BAY
ANACORTES
FIDALGO BAY
Noutical Miles
1 1/2 0 1
LEGEND
① Scott Paper Company pulp mill
② City of Anacortes sewage treatment plant
③ Sebastian Stuart Fish Co. cannery
④ Fishermen's Packing Corp. cannery
⑤ Shell Oil Company oil refinery
⑥ Texaco Inc. oil refinery
◀ Point of waste discharge

FIGURE 17-1. Waste sources in the Anacortes area.

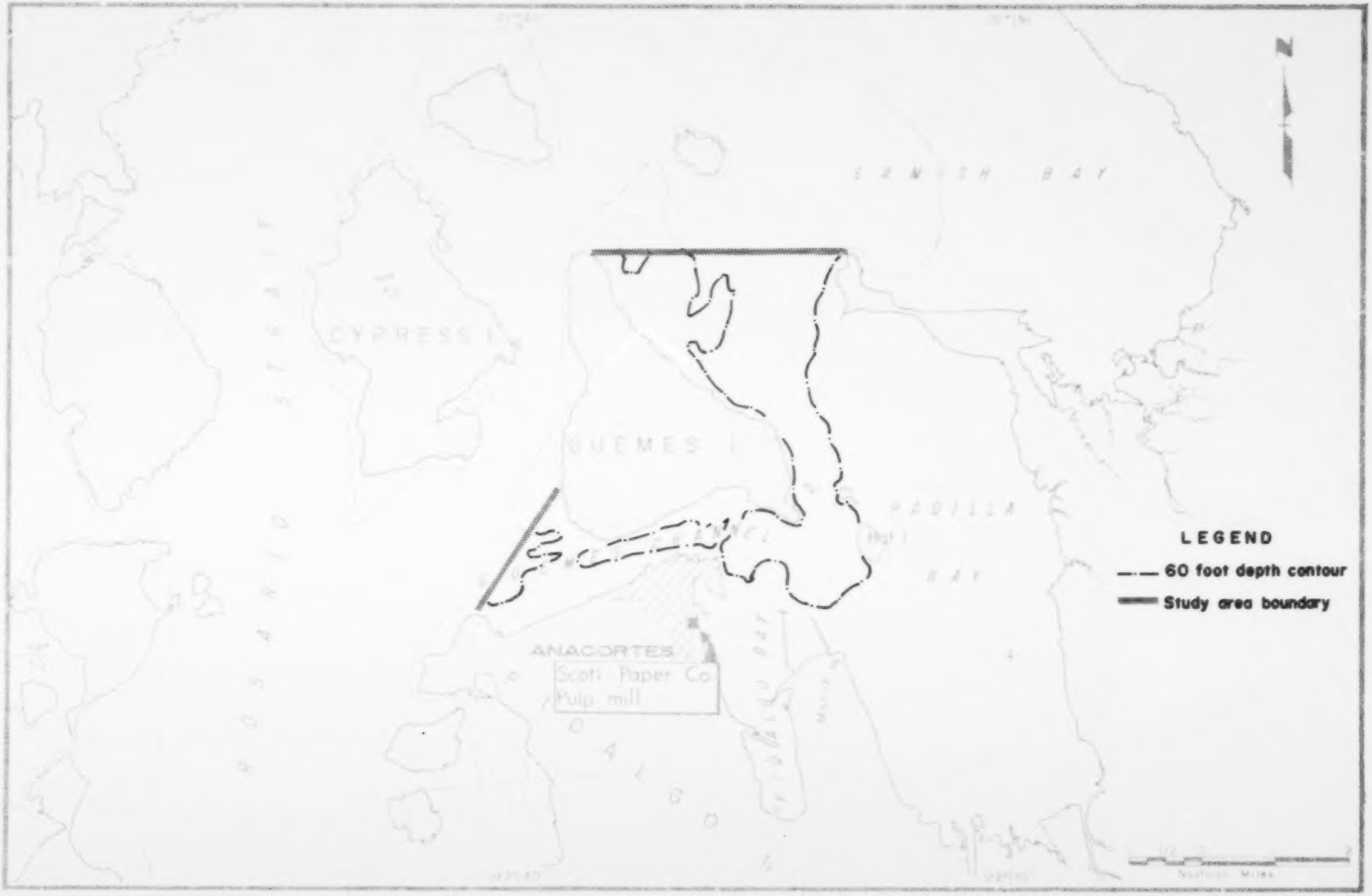

N
SAMISH BAY
CYPRESS I.
GUEMES I.
PADILLA BAY
GUEMES CHANNEL
FIDALGO BAY
ANACORTES
Scott Paper Co.
Pulp mill
FIDALGO
LEGEND
60 foot depth contour
Study area boundary
Nautical Miles

FIGURE 17-2. Anacortes study area.

18. WASTES

STUDIES

In-plant waste surveys were conducted at the Scott Paper Company mill during May 18-21, 1964, and February 8-11, 1965. In each survey, three 24-hour composite samples and additional grab samples were collected from the sewer line carrying the mill's total waste load to Guemes Channel (Figure 18-1). Both surveys were conducted, jointly, by personnel of the Project, the State, and the Scott mill.

The State surveyed the Anacortes sewage treatment plant during April 26-27, 1965, and the Sabastian Stuart Fish Co. on April 26, 1965. Waste data submitted regularly to the State by the Texaco and Shell refineries provided information on these two waste sources.

METHODS

Procedures and methods employed in the Scott mill surveys were the same as those described in Section 6. Analyses of samples collected by the State were the same as those described in Section 6.

RESULTS

Scott Paper Company. This mill employs the ammonia-base sulfite process to produce about 138 tons per day of short-fiber pulp. Pulp is bleached, dried, and baled for shipment to other mills, but principally to the Scott Paper Company mill at Everett.

Preceding page blank

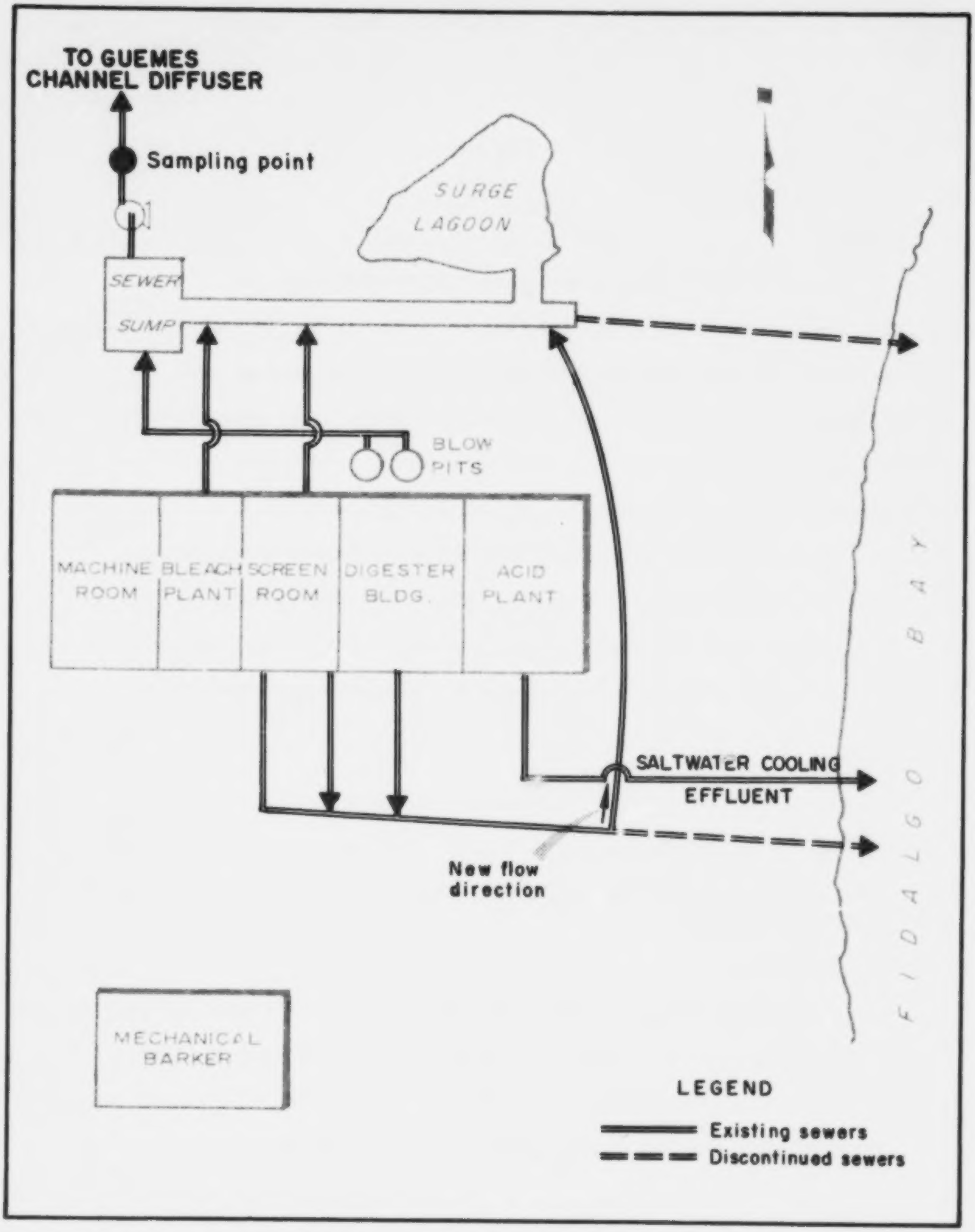

TO GUEMES CHANNEL DIFFUSER
Sampling point
SURGE LAGOON
SEWER SUMP
BLOW PITS
MACHINE ROOM
BLEACH PLANT
SCREEN ROOM
DIGESTER BLDG.
ACID PLANT
SALTWATER COOLING EFFLUENT
New flow direction
FIDALGO BAY
MECHANICAL BARKER
LEGEND
Existing sewers
Discontinued sewers

FIGURE 18-1. Mill layout and sewer system; Scott Paper Company, Anacortes, Washington.

No paper is produced. Barking of logs is accomplished by mechanical means, thus no water-borne barking wastes are generated.

A schematic diagram of the mill layout and sewer system is shown in Figure 18-1. Formerly, two sewers (dashed lines) discharged a portion of the mill's wastes into Fidalgo Bay, and a force main discharged strong wastes into Guemes Channel. In January 1964, the mill altered this system to divert all pollutional wastes, via force main, to Guemes Channel. Now, the only flow normally reaching Fidalgo Bay is uncontaminated saltwater used for cooling purposes in the acid plant.

Average results of the two surveys -- the average daily waste load discharged into Guemes Channel -- are tabulated in Table 18-1.

Anacortes Sewage Treatment Plant. This primary treatment plant with effluent chlorination treats combined wastes for an estimated population of 7,000. Treated wastes are discharged into Guemes Channel (see Figure 17-1).

A 24-hour composite sample of effluent was collected. Results are tabulated in Table 18-2.

Sabastian Stuart Fish Co. This plant cans salmon in season. Operation is intermittent and daily production varies. Wastes are screened and discharged into Guemes Channel (see Figure 17-1).

A 7-hour composite sample of screened wastes was collected on a day when the plant operated at one-third capacity and processed about 72,000 pounds of salmon (processed weight) in 11 hours operation. Results, as interpolated for full capacity and 16-hours daily operation, are given in Table 18-2.

TABLE 18-1. Average daily waste load discharged by the Scott Paper Company at Anacortes, Washington.

Analyses	#/Ton of Production	Tons/Day
BOD_5	989	68
COD	3,437	237
SWL*	27,980	1,924
Total Sulfur	161	11.1
Total Solids	2,671	184
Volatile	2,417	167
Suspended Solids	77.4	5.3
Volatile	76.5	5.2
Supernatant Susp. Solids	14.2	1.0

Ave. Tons Production/Day (air dried)	138
Ave. % Volatile Susp. Solids Loss	3.8
Ave. Waste Volume, mgd.	5.8

* Weight of a 10% solids solution, per ton or per day as indicated.

Fishermen's Packing Corp. This plant packs various types of fish in season. Operation is intermittent and daily production varies. Wastes are screened and discharged into Guemes Channel (see Figure 17-1).

This plant was not sampled. However, it is estimated that waste loads at full production are about equal to those for the Sabastian Stuart Fish Co. (see Table 18-2).

TABLE 18-2. Average daily waste loads discharged by other major waste sources in the Anacortes area.

	Tons/Day	
Analyses	Anacortes Sewage Treatment Plant	Sabastian Stuart Fish Co.
BOD_5	0.4	1.3
Total Solids	0.1	10.6
Volatile	<0.1	7.6
Suspended Solids	<0.1	1.1
Volatile	<0.1	<0.1
Waste Volume, mgd.	0.9	0.1

Texaco and Shell Refineries. Both of these refineries operate modern, well designed, and well operated secondary treatment facilities. Treated wastes are discharged into Guemes Channel and Fidalgo Bay (see Figure 17-1).

Under provisions of the permanent industrial permits issued by the State, these refineries are required to monitor and report the quantity and quality of their effluent discharges. These data, as currently reported, are listed in Table 18-3. In all categories, both industries meet the effluent requirements also prescribed by their industrial waste permits; therefore, the State considers their waste treatment practices as adequate.

TABLE 18-3. Quantity and quality of treated effluents discharged by the Shell and Texaco refineries at Anacortes.

Property	Texaco	Shell
Average daily flow (MGD)	3.0	2.1
Maximum daily flow (MGD)	12.0	9.2
Average daily pH	7.1	6.8
Maximum pH range	6.4-8.4	5.0-8.4
Average daily phenol (mg/l)	0.02	0.08
Maximum daily phenol (mg/l)	0.15	0.11
Average sulfides (mg/l)	< 0.1	nil
Average mercaptans (mg/l)	< 0.1	nil
Average daily total-oil (mg/l)	4.3	4.6
Maximum total-oil (mg/l)	15	15

DISCUSSION

At the time of the conference in 1962, the Scott mill was discharging considerable quantities of wastes into Padilla Bay. Weak circulation in the Bay provided inadequate dispersion and dilution of these waters; consequently the Bay was being polluted. For this reason, the Scott mill and the Anacortes area were considered in the Project's studies.

To abate pollution of Padilla Bay, the mill diverted all wastes except cooling wastes to Guemes Channel. This change was made to take advantage of the waste transport and dispersion capacities of the

Channel. The mill presently provides no waste treatment. Primary treatment facilities will remove some 4 tons/day of settleable solids now discharged to the Channel.

The State considers as adequate the waste treatment and disposal practices of the Anacortes sewage treatment plant and the Shell and Texaco refineries. On the other hand, waste screening practiced by the two fish canneries is recognized as being inadequate. The primary treatment of the cannery wastes will significantly reduce the settleable solids discharged to the Channel.

19. WASTE DISTRIBUTION AND WATER QUALITY

STUDIES

To describe the dispersion of wastes discharged by the Scott mill and to determine the effects of these wastes on water quality, the Project undertook oceanographic and related investigations in the Anacortes area. These involved field studies by the Project, and literature search and evaluation of the considerable body of information collected in studies by State agencies and the University of Washington. Many of these studies were a part of investigations conducted in the Bellingham area.

Circulation Studies. The Project conducted a surface-current float study on November 17, 1962 to investigate the large eddy current in Guemes Channel near the entrance to Fidalgo Bay. Crossed-vane current drogues, each suspended three feet below a marker buoy, were used. The course traveled by each float was determined using a sextant.

The U. S. Coast and Geodetic Survey (U.S.C.&G.S.) collected current data at six stations (Figure 19-2) in the Bellingham-Anacortes area during 1964-65. At each station, anchored meters were employed to monitor current speed and direction at each of three depths for a 100-hour period.

The Washington Pollution Control Commission (Wagner and Ice, 1958) conducted a comprehensive current study in August 1958. Floats were released at numerous locations in Guemes Channel and in Padilla and Fidalgo Bays during various tidal phases on nine different days.

Preceding page blank

Special attention was given to the vicinity of Scott mill's waste outfall in the Channel. Water samples for SWL, salinity, and phenol analysis were collected also.

The Washington State Department of Fisheries (McKinley, 1959) did a tidal current survey in Swinomish Slough during March-April 1958. The purpose of this study was to obtain data for estimating the volume of Padilla Bay tidal water supplied through the Slough.

Waste Distribution and Water Quality Studies. The Washington State Department of Fisheries and the Washington Pollution Control Commission each conducted water sampling cruises in the Anacortes area as a part of investigations in the Bellingham area. These studies are described in Section 7, and sampling stations are shown in Figures 7-1B and 19-1A.

The Project conducted a water sampling cruise in the Anacortes area on November 17, 1962, and routinely collected water samples in the plankton ecology study (see Section 22) conducted between July 1963 and July 1964. Sampling stations for both studies are shown in Figure 19-1B. Depths sampled were 0, 5, 10, and 25 meters, and water properties measured were temperature, salinity, DO, pH, and SWL. Water clarity, wind, and weather also were noted.

METHODS

Study methods followed by the Project were the same as those described in Section 7. Methods used by the University and State agencies were similar to those employed by the Project.

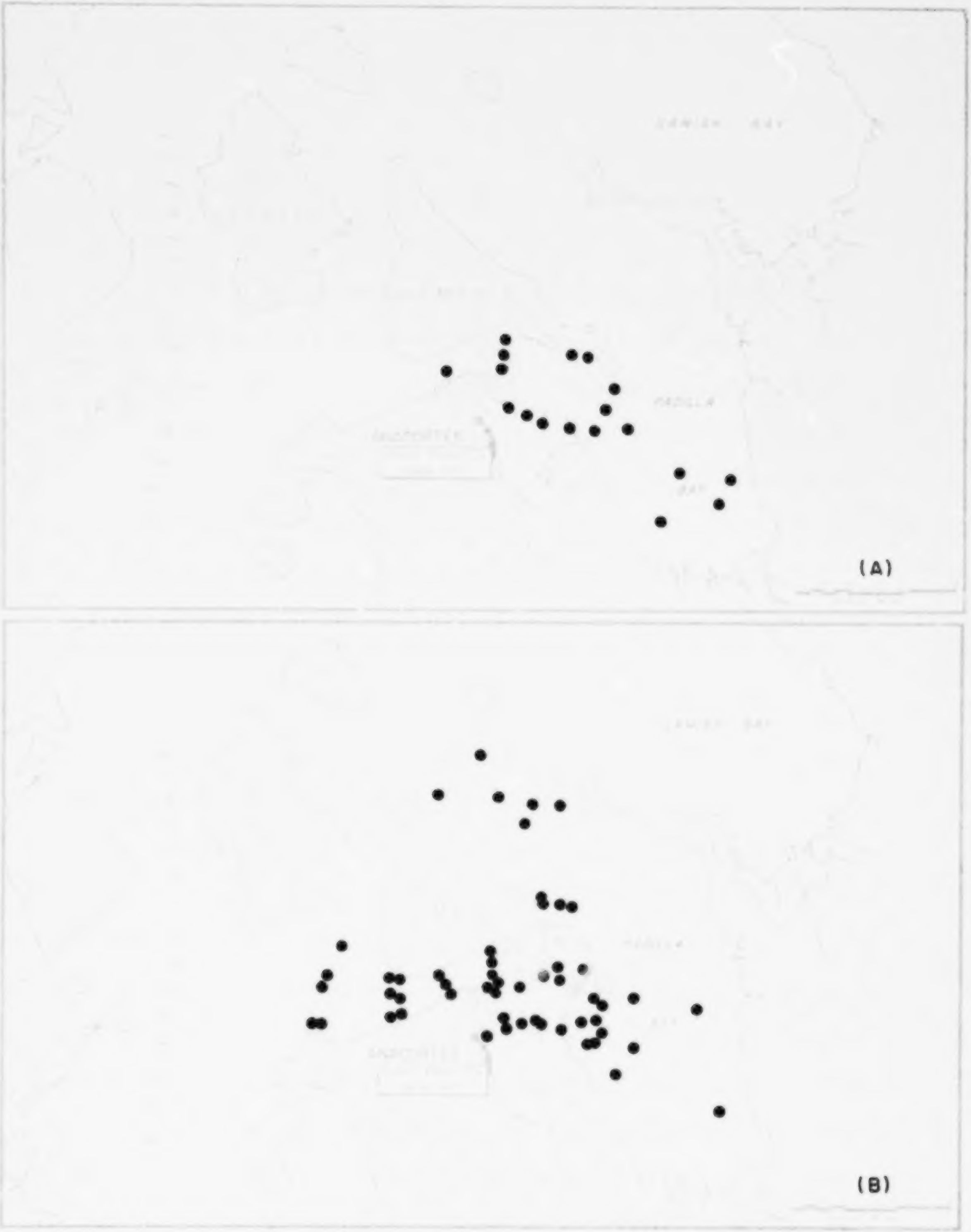

SAMISH BAY
PADILLA
BAY
ANACORTES
(A)
SAMISH BAY
PADILLA
ANACORTES
(B)

FIGURE 19-1. Water sampling stations in the Anacortes area: (A) Washington Pollution Control Commission, 1957-58 studies, (B) Project, 1962-1964 studies.

RESULTS

Net Circulation. Net water circulation in the Anacortes area is described in Figure 19-2. Although this pattern, based on current data collected by U.S.C.&G.S. in their 1964-65 survey, describes only surface conditions, similar net circulation was observed at depth. Note that a net drift of water from the Bellingham-Samish Bay system enters Padilla Bay and flows southward through the Bay, westward through Guemes Channel, and out into Rosario Strait. This net pattern results from the predominance of ebb tide transport over flood tide transport. The importance of this net circulation pattern is two-fold: (1) the net drift of water from the Bellingham-Samish Bay system carries, into the Anacortes area, dispersed wastes originating at the Georgia-Pacific mill, and these wastes influence water quality in Padilla-Fidalgo Bays; and (2) the net transport of water through Guemes Channel effectively flushes Scott mill wastes out of the study area. This flushing is comparatively rapid, for the mean travel time to move wastes from the Scott mill outfall to the west end of Guemes Channel is estimated to be 4 hours.

Tidal Currents. Prevailing tidal currents in Guemes Channel are usually strong. At the west end of the Channel, the average maximum ebb velocity is about 2.1 knots, and the average maximum flood velocity is about 0.9 knots (U.S.C.&G.S., 1966). These strong currents result from the large amounts of water required in the twice-daily emptying and filling of the Padilla-Fidalgo Bay tidal volume passing through the relatively narrow and shallow cross-section of the Channel. These strong currents effect rapid and effective dilution of the Scott mill wastes discharged into the Channel.

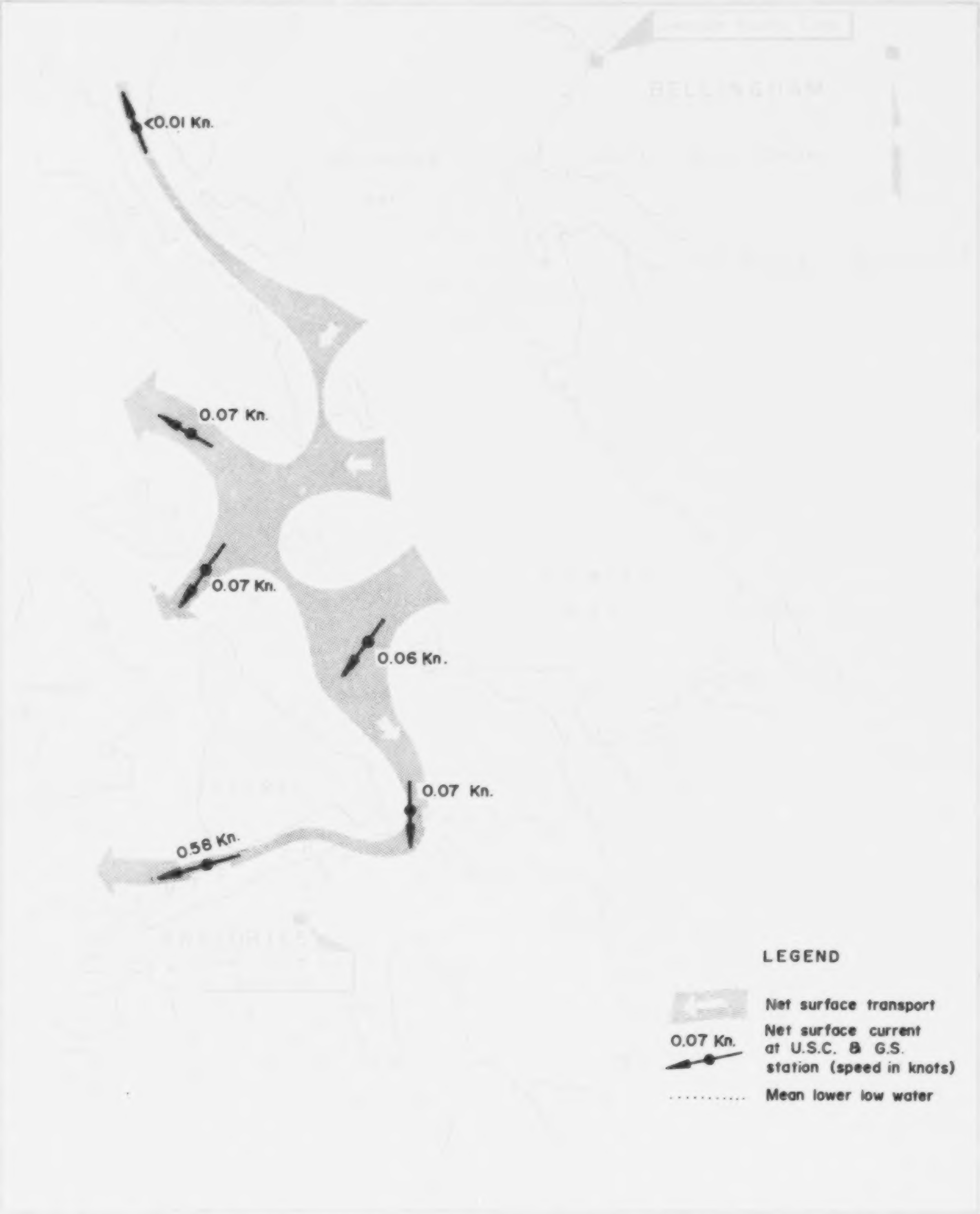

BELLINGHAM
<0.01 Kn.
0.07 Kn.
0.07 Kn.
0.06 Kn.
0.07 Kn.
0.58 Kn.
LEGEND
▨ Net surface transport
0.07 Kn. Net surface current at U.S.C. & G.S. station (speed in knots)
.... Mean lower low water

FIGURE 19-2. Net surface circulation pattern and net surface currents in the Bellingham-Anacortes area. data from U.S.C.&G.S. current meter studies of 1964-65.

Guemes Channel Eddy. Typical flood and ebb surface current patterns in the Anacortes area are shown in Figure 19-3. Of special importance is the large, generally clockwise, surface eddy at the east end of Guemes Channel where it adjoins Fidalgo and Padilla Bays. This eddy, present during both flood and ebb tides, is characterized by numerous tide-rips and surface turbulence. Based on observations of several floats released near the Scott mill outfall in Guemes Channel (Wagner and Ice, 1958), this eddy appears to limit the flood excursion of Scott mill wastes into Padilla and Fidalgo Bays. Furthermore, it effects rapid dilution and mixing of these wastes with Channel waters.

Waste Distribution. Wastes from the Scott mill enter Guemes Channel via a submerged, 15-port diffuser pipeline discharging at a depth of 30 feet at the point shown in Figure 19-4. Effluent is evident as a small, surface patch of highly colored water over the outfall and under the adjacent docks where circulation is poor. From this effluent boil, wastes are rapidly dispersed, both vertically and laterally, throughout the Channel. Surface water samples taken along the path-of-movement of floats released over the outfall showed a logarithmic decrease in waste concentrations from 3,000-10,000 ppm SWL at the outfall to 50-250 ppm SWL one-half nautical mile away (Wagner and Ice, 1958). SWL values measured at points one mile and more from the outfall were, in almost all cases, less than 10 ppm.

There appears to be little transport of Scott mill wastes into Padilla and Fidalgo Bays. Data collected in the 27 cruises by the Washington Department of Fisheries show average SWL levels of less than 3 ppm--background levels--throughout these two Bays. Maximum

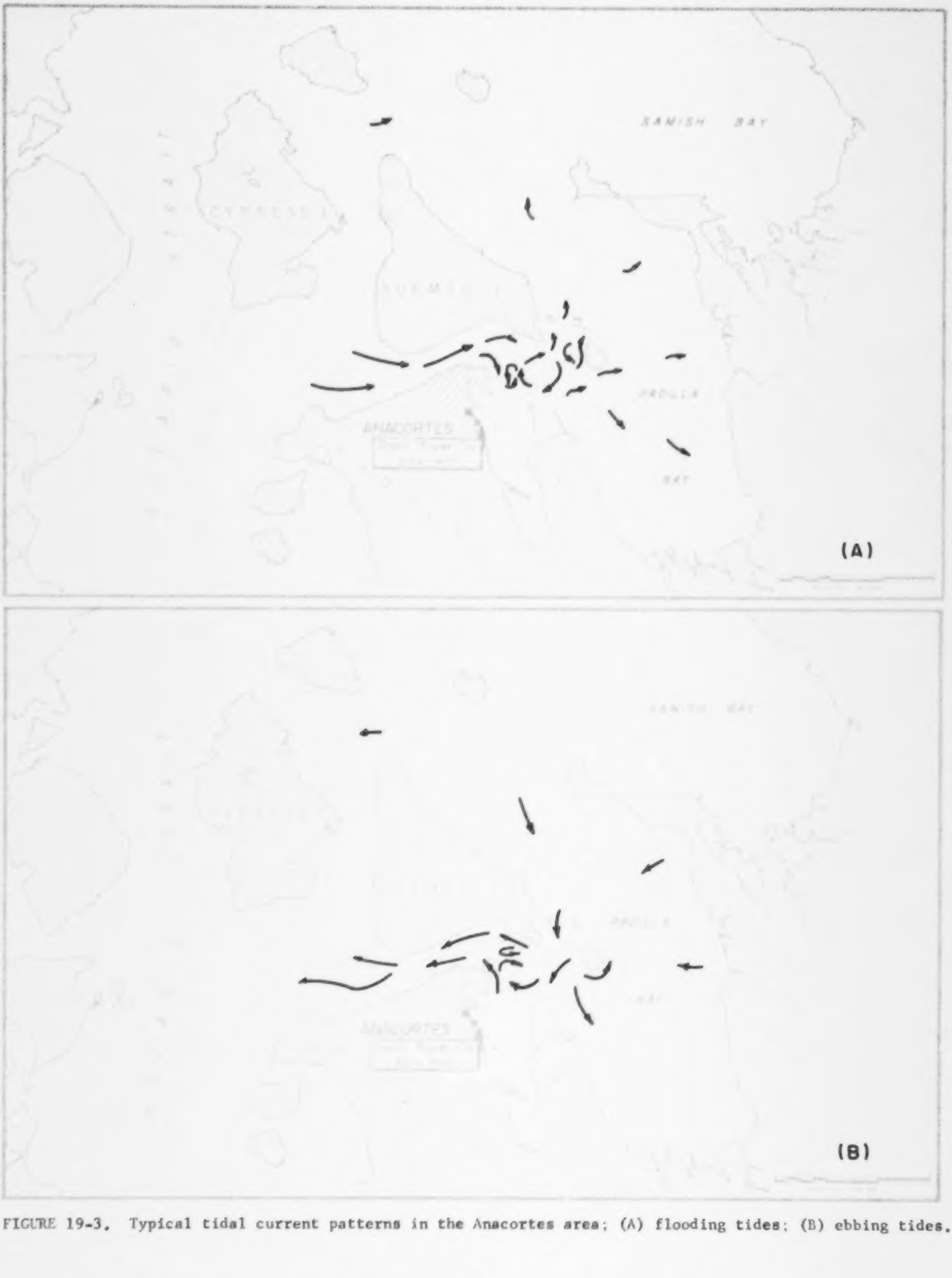

SAMISH BAY
CYPRESS
GUEMES
ANACORTES
PADILLA
BAY
(A)
SAMISH BAY
PADILLA
BAY
ANACORTES
(B)

FIGURE 19-3. Typical tidal current patterns in the Anacortes area; (A) flooding tides; (B) ebbing tides.

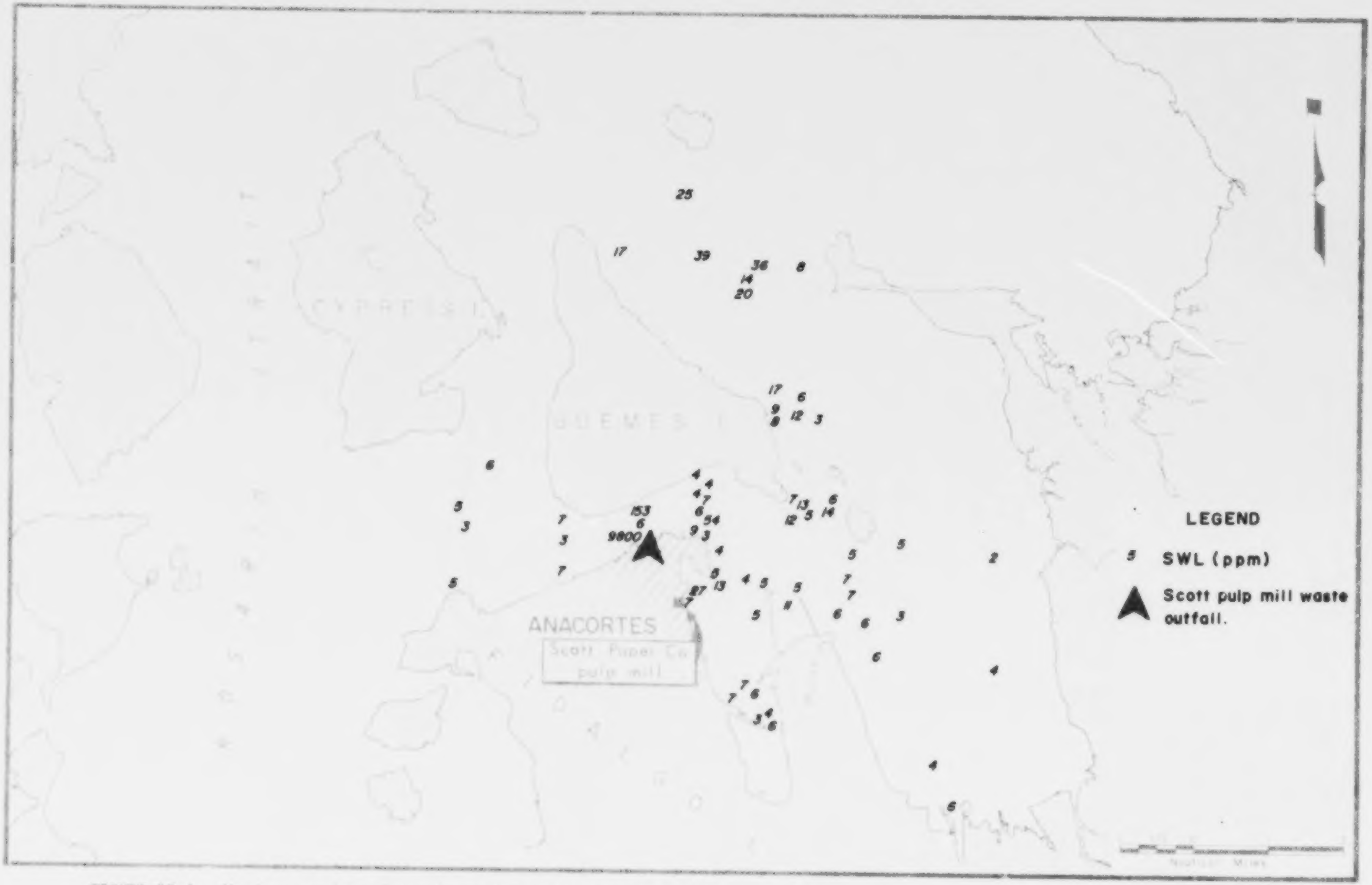

LEGEND
5 SWL (ppm)
Scott pulp mill waste outfall.
ANACORTES
Scott Paper Co. pulp mill
GUEMES I.
CYPRESS I.
Nautical Miles
25
17
39
36
14
20
8
9800
153

FIGURE 19-4. Maximum surface SWL values observed in the Anacortes area; data from all oceanographic studies 1957 - 1964.

SWL observations in these waters (Figure 19-4) seldom exceeded 7 ppm, except as noted below.

Maximum SWL values observed in all surveys are shown in Figure 19-4. The higher maxima noted in the northern part of Padilla Bay (as far south as the southeastern tip of Guemes Island) evidence the inflows of dispersed wastes from the Bellingham-Samish Bay system. On the dates of their observation, these maxima were associated with a progression of higher SWL concentrations northward but low SWL values to the south and west, thus describing the southward distribution of Georgia-Pacific mill wastes rather than the northeastward distribution of Scott mill wastes.

Water Quality. Measurements of dissolved oxygen, pH, water transparency, and phenols were made on various cruises in the Anacortes area. Except in samples taken immediately adjacent to the outfall, all values of these water quality properties approached those of the ambient sea water. Dissolved oxygen values approaching zero were occasionally observed over the outfall but were of localized extent and did not appear to persist beyond the immediate outfall vicinity.

DISCUSSION

The hydraulic characteristics of Guemes Channel--strong tidal currents, net ebb-flow flushing, and eddy mixing and dilution--cause this body of water to be nearly ideal for waste disposal. Scott mill wastes are so rapidly dispersed that they have a significant effect on water quality only in the vicinity of their discharge and have a subtle, but detectable, effect on water quality only within one mile of their discharge. In Padilla and Fidalgo Bays, it has not been positively shown that these wastes influence water quality; only near-background levels of SWL are evident in these waters.

In spite of this excellent dispersion and dilution of discharged wastes, the present practice of disposing wastes without diffusion into the near-surface waters of Guemes Channel is considered to be unsatisfactory. This disposal system produces waste concentrations of from 10-10,000 ppm SWL in the vicinity of the outfall, and these concentrations are injurious to marine life (see following Sections 20, 21, and 22). Further, it produces a surface patch of highly colored, aesthetically displeasing wastewater over the outfall and under the docks fronting the City of Anacortes. These conditions, however, can be alleviated by discharging present waste flows through a deep-water diffuser to the accomplishment of better utilization of the excellent assimilative capacity of the Channel. Diffuser discharge would effect jet mixing, and deep-water discharge would effect buoyant mixing and would place the wastes at depths where net ebb-flow flushing is more pronounced. Waste concentrations in the near-surface waters of the Channel would be markedly reduced, providing (1) acceptable water quality for the more sensitive marine forms--plankton, and embryonic and larval forms--commonly inhabiting near-surface waters and (2) enhancement of aesthetic quality along the City's waterfront.

20. OYSTER LARVAE

The oyster-larva study in the Anacortes area was part of that study conducted in the Bellingham area and is described in Section 11. Briefly, between May 1963 and August 1965, surface water samples were collected at monthly intervals at six stations (Figure 20-1A). These were flown to the State's Shellfish Laboratory for bioassay with Pacific oyster larvae by the procedures previously described. In addition to this regular program, two special bioassay investigations were conducted to evaluate water-quality changes associated with closures of the Scott mill during July 6-12 and November 12-26, 1964, and a waste-sample study was conducted on a 24-hour composite sample of total waste flow (see Section 11 for discussion and results).

RESULTS

As stated in Section 11, the statistical analyses of results from this study show that SWL is the dominant factor associated with the primary response measurement--larval abnormality.

Larval Abnormality. The relationship between SWL and larval abnormality, as observed in the combined Bellingham-Anacortes area, is shown in Figure 11-5. The results given reflect the removal of the data from certain samples (see Table 11-1); thus, this curve shows only the effects of dispersed mill wastes on the development of oyster larvae. Note that significant increases in percent abnormality begin at SWL values of 10 ppm.

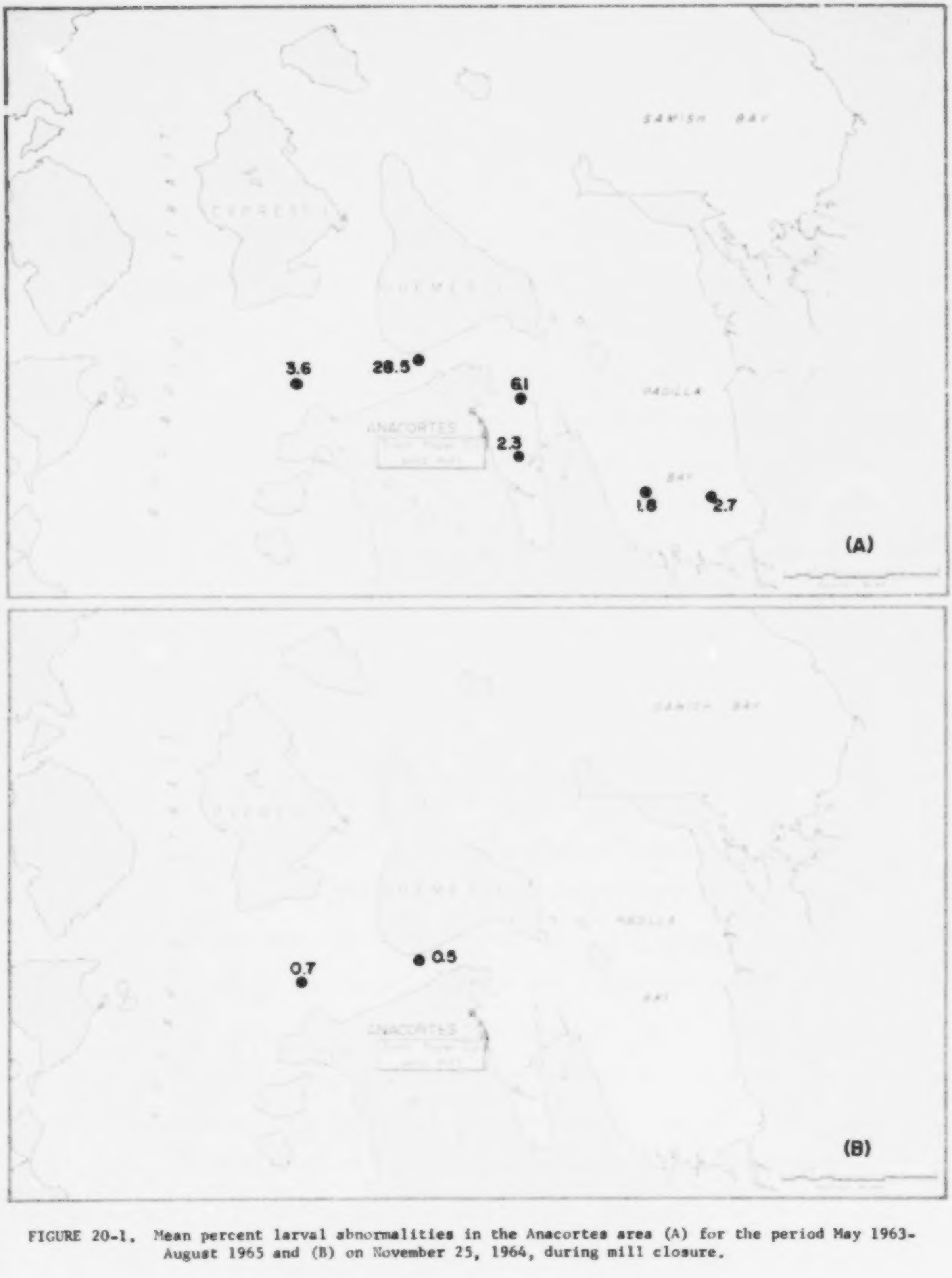

SAMISH BAY
3.6
28.5
6.1
PADILLA
ANACORTES
2.3
BAY
1.8
2.7
(A)
SAMISH BAY
PADILLA
0.7
0.5
BAY
ANACORTES
(B)

FIGURE 20-1. Mean percent larval abnormalities in the Anacortes area (A) for the period May 1963-August 1965 and (B) on November 25, 1964, during mill closure.

Figure 20-1A shows mean percent larval abnormalities by station for the Anacortes area. Note (1) the high abnormality level at Station 14, near the discharge point for Scott mill wastes and (2) the comparatively low mean abnormality levels at all other stations in the study area. Associated mean SWL levels show a similar relationship; *i.e.*, a mean of 110 ppm at Station 14 compared with mean levels of 3 ppm or less at each of the other stations. These results indicate the relatively rapid dispersion of Scott mill wastes in Guemes Channel. Waste concentrations and their injurious effect on oyster larvae are critically high only in the vicinity of the waste outfall and are relatively low throughout the rest of the study area.

Results obtained from the samples collected at Station 14 fall into two distinct classes of data: (1) low abnormalities associated with low SWL values and (2) high abnormalities associated with high SWL values. These results are shown in Table 20-1. At this station, under certain tide conditions, sampling was within the effluent discharge zone of the Scott diffuser, and these samples were high in SWL and produced high larval abnormalities when bioassayed. Under different tide conditions, sampling was outside the effluent discharge zone, and the waste dispersion in Guemes Channel resulted in samples which were low in SWL and produced low larval abnormalities when bioassayed. It is significant that water taken from the same station caused widely different degrees of injury to oyster larvae depending on the concentration of pulping wastes.

TABLE 20-1. Associated values of SWL and larval abnormality for samples collected at Station 14 in the Anacortes area.

SWL (ppm)	Low Values of Larval Abnormality (%)	SWL (ppm)	High Values of Larval Abnormality (%)
1	0.0	31	73.5
1	0.6	49	99.5
1	1.6	54	100.0
2	0.5	55	100.0
2	2.2	138	100.0
2	2.3	180	99.1
2	6.6	270	100.0
3	2.6	362	100.0
6	0.5	1,470	100.0
Ave. 2	1.9	290	96.9

It should be noted that for Station 14 the mean percent of abnormals during the study (see Table 11-1 and Figure 20-1A) does not describe the conditions to be expected at this station at any one time. Instead of the mean, either a percent of abnormals near 100 or a percent of abnormals near 0 would be most likely. Similarly, under certain conditions of waste dispersion, abnormalities at Stations 15 and 16 were well above the mean levels shown in Figure 20-1A, and, occasionally, exceeded 20%.

Larval Abnormality During Mill Closure. During the period November 12-26, 1964, a labor strike stopped production at the Scott mill, and waste discharge into Guemes Channel ceased. To assess water quality changes accompanying this closure period, field samples for bioassay were collected from two stations (Figure 20-1B) before, during, and after closure. A description of this special study and its results are given in Section 11.

Results show that mill closure produced significant decreases of both larval abnormality and SWL at the two stations and that resumption of production produced significant increases of both larval abnormality and SWL to levels regularly observed (see Table 11-1). Figure 20-1B shows the larval abnormalities observed at both stations on November 25, after 13 days of closure. These very low levels of abnormality may be considered as background levels of natural occurrence and they were associated with background SWL levels of less than 1 ppm.

DISCUSSION

Although the mean levels of oyster larva abnormality seen throughout most of the Anacortes study area are moderately low (Figure 20-1A), the results obtained during mill closure indicate that the abnormalities observed, nonetheless, are caused by the pulping wastes from the Scott mill.

While present disposal practices limit the effect of the Scott mill wastes, the occasional high levels of abnormalities observed at stations some distance from the waste source (Stations 15 and 16) indicate that the full assimilative capacity of Guemes Channel is not being utilized. The tremendous volume of dilution water needed to reduce the toxicity of these wastes to non-harmful levels is discussed in Section 11 and is shown in Table 11-5. Therefore, it is recommended that more adequate diffusion of mill wastes be provided (see Section 19).

21. SUMMARY

The Scott Paper Company pulp mill located in Anacortes is the major source of wastes now discharged to Guemes Channel. Pulping wastes are pumped to the Channel from the mill site located on Padilla Bay. The tidal currents in Guemes Channel provide conditions which are well suited to assimilate residual waste discharges. However, pulping wastes discharged by the Scott Paper Company mill do adversely affect water quality in the immediate waste dispersion zone. This effect can be significantly reduced by extending the outfall and diffuser section to a greater depth, thereby providing greater initial dilution. Settleable solids materials in the waste discharge probably do not settle in the immediate discharge zone but are carried to outer channel limits and deposited. Nevertheless, removal of these materials is considered a prerequisite prior to discharge to coastal waters.

Fish processing wastes are discharged into Guemes Channel by Fishermen's Packing Corp. and Sebastian Stuart Fish Co. on a seasonal basis. The wastes discharged contain significant quantities of settleable solids.

Domestic wastes from the City of Anacortes receive primary treatment plus chlorination prior to discharge to Guemes Channel.

Preceding page blank

Part 4

EVERETT STUDIES

Preceding page blank

22. INTRODUCTION

The waste sources of principal consideration in the Everett area are the Scott Paper Company sulfite pulp and paper mill, the Weyerhaeuser Company sulfite pulp mill, and the Simpson Lee Paper Company kraft pulp and paper mill. All three are located in the City of Everett (see Figure 22-1). The first two discharge process wastes into the Everett Harbor and Port Gardner; the latter discharges process wastes into the Snohomish River at a point nine miles above its mouth.

Other major waste sources in the area are the City of Everett stabilization pond, two Weyerhaeuser Company lumber mills, and the Weyerhaeuser Company kraft pulp mill (see Figure 22-1).

STUDY AREA

The Everett study area (see Figure 22-2) includes Saratoga Passage, Port Susan, Possession Sound, Port Gardner, and the lower 10-miles of the Snohomish River. Where divisions between these bodies of water are not well defined, arbitrary boundaries are shown.

Saratoga Passage adjoins Possession Sound on the south and Skagit Bay (not shown) on the north. It is a deep steep-sided body of water. Offshore depths range from 200 feet to nearly 600 feet. For all practical purposes, Saratoga Passage is a basin opened at only one end, opening to Possession Sound to the south.

Preceding page blank

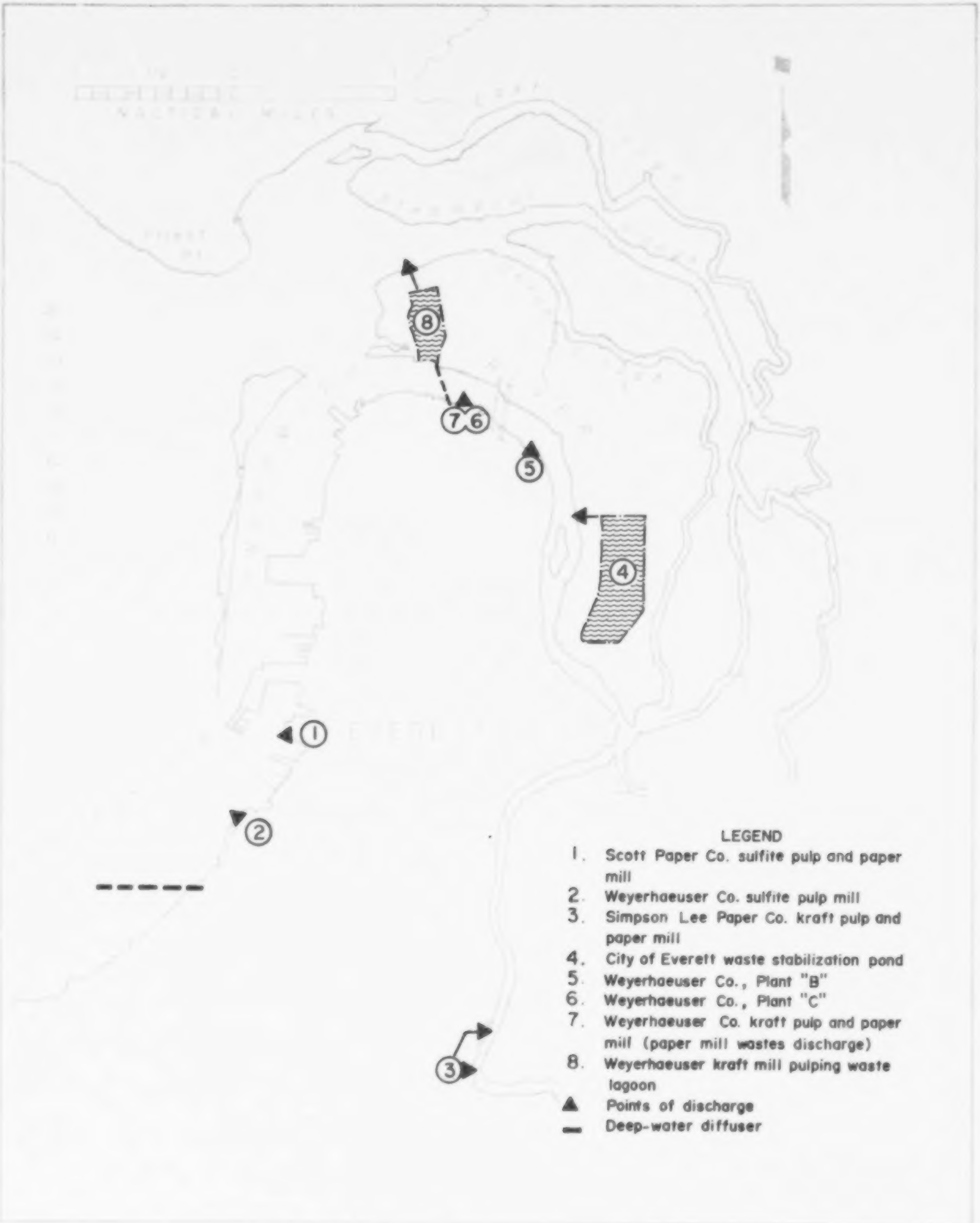

NAUTICAL MILES
EVERETT
LEGEND
1. Scott Paper Co. sulfite pulp and paper mill
2. Weyerhaeuser Co. sulfite pulp mill
3. Simpson Lee Paper Co. kraft pulp and paper mill
4. City of Everett waste stabilization pond
5. Weyerhaeuser Co., Plant "B"
6. Weyerhaeuser Co., Plant "C"
7. Weyerhaeuser Co. kraft pulp and paper mill (paper mill wastes discharge)
8. Weyerhaeuser kraft mill pulping waste lagoon
▲ Points of discharge
▬ Deep-water diffuser

FIGURE 22-1. Waste sources in the Everett area.

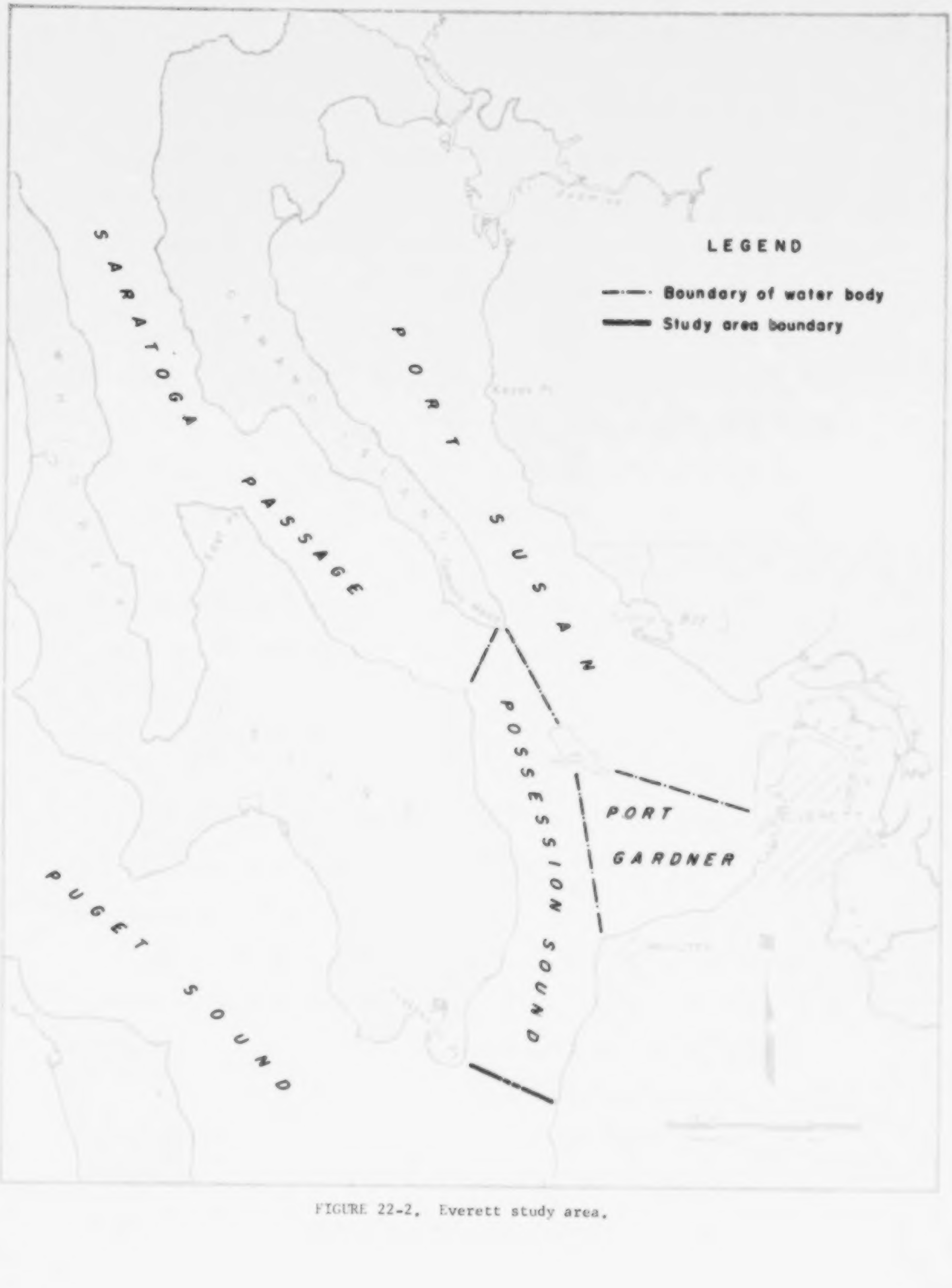

LEGEND
Boundary of water body
Study area boundary
SARATOGA PASSAGE
PORT SUSAN
POSSESSION SOUND
PORT GARDNER
PUGET SOUND

FIGURE 22-2. Everett study area.

Port Susan also is opened at only one end, opening to Port Gardner and Possession Sound to the south. Shallow waters occur at its northern end, over the delta formed by the Stilliguamish River, and in its southern part, over the delta formed by the Snohomish River. Otherwise, it is steep-sided and deep (200 to 360 feet). It adjoins Possession Sound over a sill between Camano Head and Gedney Island and adjoins Port Gardner over a sill east of Gedney Island (see the 225-foot depth contour, Figure 22-3).

Possession Sound is a deep, steep-sided channel connecting the study area to other parts of Puget Sound. Offshore depths range from 200 feet to over 600 feet.

Port Gardner is an arm of Possession Sound. Depths throughout most of the Port range from 200 to 600 feet. More shallow waters occur along its northern boundary; in the region of Gedney Island, in the vicinity of the Inner Harbor, and over the sill connecting the Port with Port Susan.

Located in the northeastern corner of Port Gardner is Everett Harbor (see Figure 22-3), a small, semi-enclosed basin having depths of 30 to 90 feet. The arbitrary boundary shown delimits the southwestern extent of the Harbor. Heavy industry, including the Scott and Weyerhaeuser mills, is located on the Harbor, and almost all deep-draft shipping for the Everett area dock in this basin. The Harbor also is a major log storage area.

Port Gardner receives all wastes discharged by the Scott and Weyerhaeuser mills. Strong wastes (mostly sulfite waste liquors) from both mills are combined and discharged directly into this body

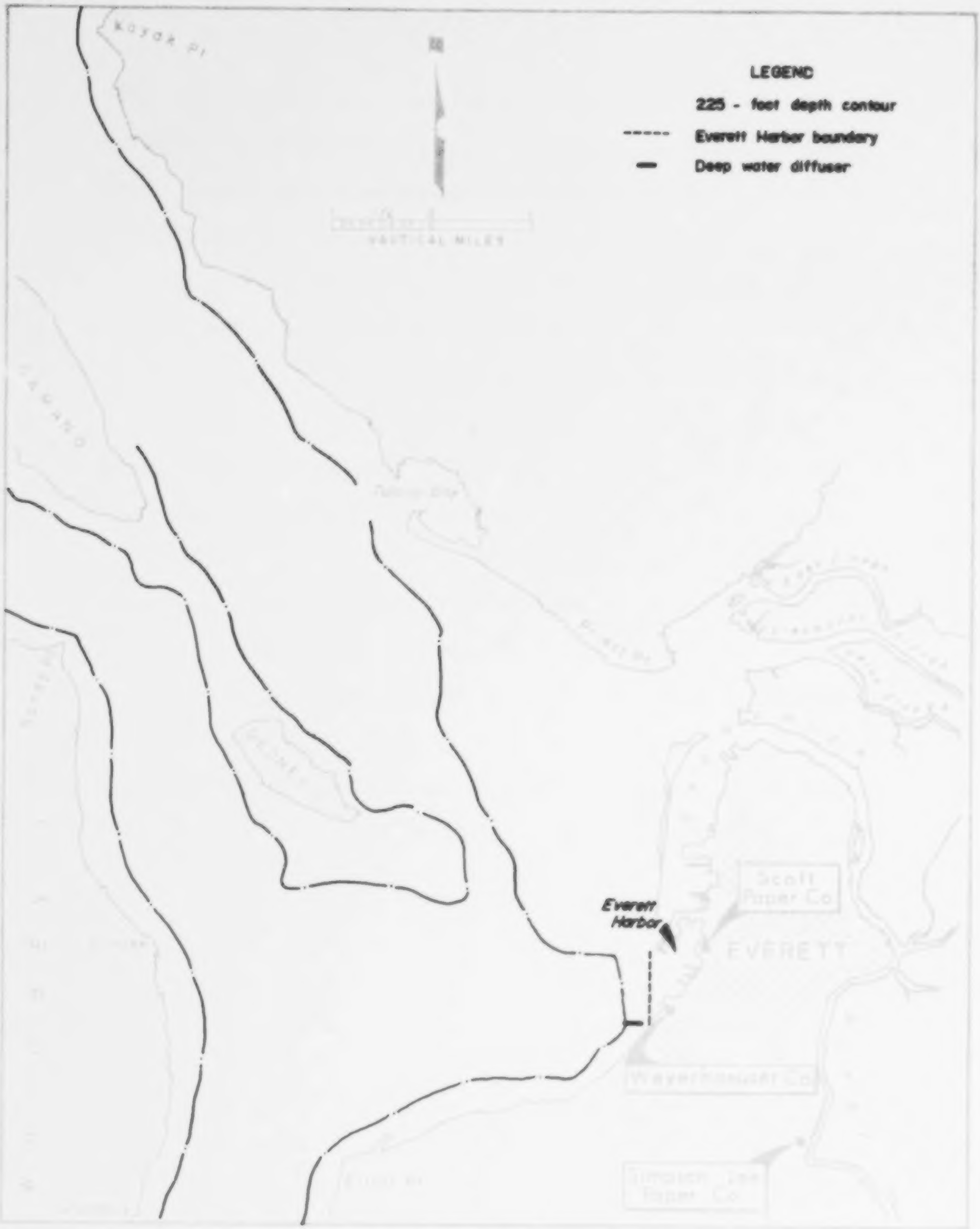

Kayak Pt
LEGEND
225 - foot depth contour
----- Everett Harbor boundary
— Deep water diffuser
NAUTICAL MILES
Everett Harbor
Scott Paper Co
EVERETT
Weyerhaeuser Co
Simpson Lee Paper Co

FIGURE 22-3. Central portion of Everett study area.

of water through a deep-water diffuser (see Figure 22-3). The diffuser portion is a multi-port pipe section, 1,000 feet long and terminating 3,000 feet offshore. It discharges wastes between the depths of 300 and 340 feet. Other process wastes from the Scott mill are discharged at depth into Everett Harbor, and other process wastes from the Weyerhaeuser mill are discharged into sub-surface waters of the Harbor. These wastes disperse into Port Gardner.

The lower part of the Snohomish River is shown, in detail, in Figure 22-3. It consists of four major channels: the main channel (designated "Snohomish River"), Union Slough, Steamboat Slough, and Ebey Slough. The three sloughs empty into Port Susan, whereas the main channel makes a U-bend, flows south inside a natural and man-made jetty, and empties into Port Gardner (although at high tides, some flow passes over the jetty and enters Port Susan). The estimated average daily discharge of the River is 10,000 second-feet and estimated extreme daily discharges are 130,000 and 90 second-feet. The main channel, which is periodically dredged for navigation, carries the largest part of the River's discharge.

23. WASTES

STUDIES

In-plant waste surveys were conducted at the principal waste sources in the Everett area on the following dates:

Scott Paper Company	April 8-11, 1963 February 24-27, 1964 August 3-6, 1964 May 17-19, 1966
Weyerhaeuser Company sulfite mill	March 11-14, 1963 January 20-23, 1964 September 14-17, 1964
Simpson Lee Paper Company	June 3-6, 1963 March 9-12, 1964

Each survey period covered 72 hours, and during this time, three 24-hour composite samples and additional grab samples were collected from each of several waste streams within each mill. These surveys were conducted, jointly, by personnel of the Project, the State, and the mill involved.

The other major waste sources of the area were surveyed by the State on the following dates:

City of Everett stabilization pond	June 3, 1965
Weyerhaeuser Company lumber mills	June 3, 1965
Weyerhaeuser Company kraft mill	January 11-14, 1965

The details of these surveys are described later.

METHODS

Survey procedures and methods of sampling and analysis were the same as or similar to those described in Section 6. Generally, composite samples were collected with automatic samplers or were made up of grab samples collected at 30-minute intervals. Sample analyses included 5- and 20-day BOD, COD, SWL, sulfur, total solids (fixed and volatile), suspended solids (fixed and volatile), Imhoff-cone settleable solids, and pH. Waste stream flows and production were reported by the mills.

RESULTS

Scott Paper Company. This mill, located on Everett Harbor (see Figure 22-1), produces calcium- and ammonia-base, paper-grade sulfite pulp and various types of towel and tissue paper. Pulp production is about 828 tons per day. About half of this is used internally in the paper mill; the remainder is market pulp for shipment to other mills. Hydraulic barking, pulp bleaching, and pulp drying and baling are part of the pulping operation. Paper production is about 528 tons per day. In addition, a refiner groundwood mill was recently added to the Company's facilities. This plant produces about 50 tons of pulp per day by a high-yield mechanical process. Its wastes contain chemicals and fiber losses, and these were measured during the fourth in-plant survey.

Figure 23-1 is a schematic diagram of the mill layout and sewer system. The heavy lines designate the new waste sedimentation facilities and interceptor sewer system put into operation in July 1965 (after completion of the first three in-plant surveys). The lighter solid and dashed lines show, respectively, the retained and discontinued parts of the sewer system that operated prior to the addition of these new treatment facilities. Survey sampling points are shown also.

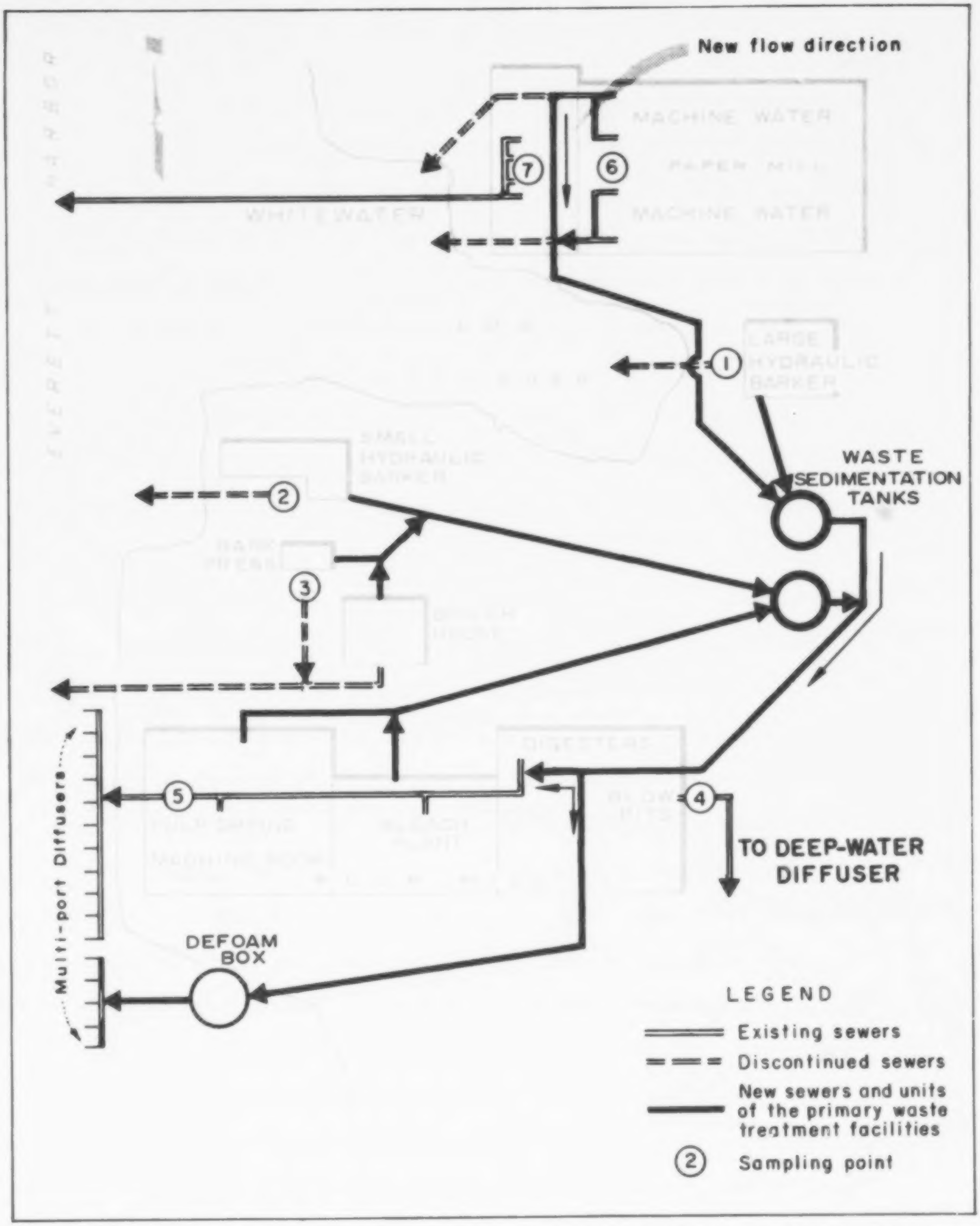

New flow direction
MACHINE WATER
PAPER MILL
MACHINE WATER
WHITEWATER
EVERETT
LARGE HYDRAULIC BARKER
SMALL HYDRAULIC BARKER
BARK PRESS
WASTE SEDIMENTATION TANKS
DIGESTERS
BLOW PITS
PULP DRYING
MACHINE ROOM
BLEACH PLANT
TO DEEP-WATER DIFFUSER
Multi-port Diffusers
DEFOAM BOX
1
2
3
4
5
6
7
LEGEND
Existing sewers
Discontinued sewers
New sewers and units of the primary waste treatment facilities
2
Sampling point

FIGURE 23-1. Schematic diagram of mill layout, sewer systems, and sampling points: Scott Paper Company, Everett, Washington.

Strong digester wastes are collected from the blow pits and discharged into Port Gardner through a deep-water diffuser, jointly owned and operated by the Scott mill and the Weyerhaeuser sulfite mill. Sanitary wastes are collected and treated by the City of Everett. All other wastes are discharged into Everett Harbor. As shown in Figure 23-1, these other mill wastes were formerly discharged through seven sewers. The new sewer system intercepts five of these sewers and collects some wastes from the pulp mill, thereby collecting the high-suspended-solids wastes within the mill for diversion to new sedimentation facilities. Therefore, present waste discharges into Everett Harbor are paper mill whitewaters, which have passed through save-alls for fiber recovery; clarified effluent from the sedimentation facilities; and low-suspended-solids wastes from the pulp mill. The latter two waste flows are discharged near the bottom of the Harbor through multiport diffusers. The new sedimentation facilities are designed to provide 2.4 hours' detention for a waste flow of 15 mgd. Sludge is mechanically collected, dewatered in a centrifuge, and burned. Centrifuge effluent is discharged back to the clarifier influent except for two hours per day when discharge is to the Harbor.

Averaged results from the first three survey are tabulated in Table 23-1. All suspended solids data derived from these surveys have been excluded from this table because (1) with present treatment, they no longer describe the mill's true discharge of suspended solids, and (2) problems with non-representative sampling induced significant errors in the suspended solids measurements taken during these early surveys. Note, in Table 23-1, that the pulp mill is the principal

TABLE 23-1. Average daily waste loads discharged by the Scott Paper Company in Everett, Washington data based on results from the first three in-plant surveys.

Analyses	Pulp Mill		Paper Mill	
	#/Ton of Production	Tons/ Day	#/Ton of Production	Tons/ Day
BOD_5	989	410	9.7	2.5
COD	4,166	1,727	25.1	6.6
SWL*	33,590	13,910	3.7	1.0
Total Sulfur	188	77.6	--	--
Total Solids	3,186	1,322	29.9	7.9
Volatile	2,792	1,158	21.0	5.6
Ave. Tons Production/Day (air dried)	828		528	
Ave. Waste Volume, mgd.	55.8		10.0	

* Weight of a 10% solids solution, per ton or per day as indicated.

contributor of BOD, SWL, sulfur, and total solids. The paper mill contributes, primarily, a suspended solids load which is reflected in the Everett Harbor waste load in Table 23-2.

In the fourth in-plant survey, attention was given to measuring the mill's total discharge of suspended solids and to evaluating the efficiency of the new sedimentation facilities. Averaged results are tabulated in Table 23-2. The Everett Harbor load derives from treated effluents, untreated paper mill whitewaters, and those low-solids pulp mill wastes not treated. The Port Gardner load derives from solids contained in the strong digester wastes discharged through the deep-water diffuser. Note that Everett Harbor receives most of the suspended solids discharged.

TABLE 23-2. Average daily suspended-solids waste load discharged by the Scott Paper Company in Everett, Washington; data based on results from the fourth in-plant survey.

Analyses	Tons/Day	
	To Everett Harbor	To Port Gardner
Suspended Solids	19.1	5.4
Volatile	17.3	5.1
Supernatant Susp. Solids	11.1	3.6

Measurements (fourth survey) of suspended solids in the influent and effluent of the new sedimentation facilities indicate the treatment efficiencies: total suspended solids, 80 to 90%; volatile suspended solids, 80 to 90%; and BOD_5, 60 to 70%. The percentage BOD_5 reduction, although substantial, affects only a small portion of the mill's total BOD_5 load, most of which derives from the strong digester wastes discharged untreated through the deep-water diffuser. In consideration of the fact that some waste streams are not provided treatment in the new sedimentation facilities, reduction of the mill's total suspended solids load is less than indicated by the above efficiencies. Based on the total raw solids load developed by the mill, but excluding the solids load discharged into Port Gardner via the deep-water diffuser, the new sedimentation facilities effect a reduction of about 60% in both total suspended solids and volatile suspended solids discharged into Everett Harbor.

Weyerhaeuser Company Sulfite Mill. This mill is located at the entrance to Everett Harbor (see Figure 22-1). It employs the calcium-base sulfite process to produce both paper and dissolving grades of pulp. Production averages about 300 tons per day. Output is shipped to customers; no paper is produced at this mill. Hydraulic barking, pulp bleaching, and pulp drying and baling are part of the pulping process.

Figure 23-2 is a schematic diagram of the mill layout and sewer system. During the first two in-plant surveys, screened wastes from the hydraulic barker were discharged to the log pond through the sewer indicated by the lighter dashed line. Subsequently, the company installed primary settling facilities for these barker wastes and began discharging clarified effluent through one of the main sewers discharging underneath the dock. These new facilities are designated

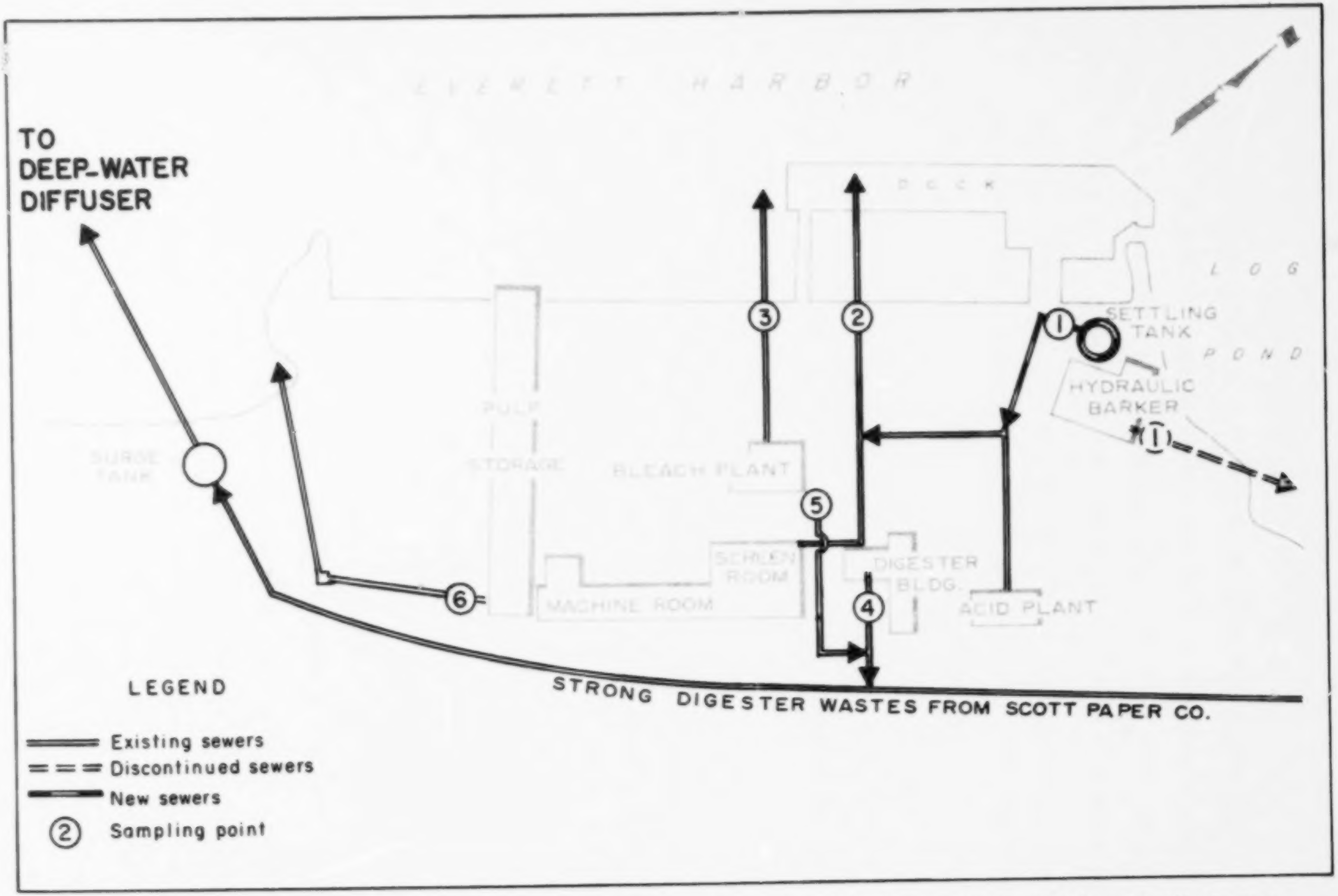

EVERETT HARBOR
TO DEEP-WATER DIFFUSER
DOCK
LOG POND
SETTLING TANK
HYDRAULIC BARKER
1
2
3
4
5
6
SURGE TANK
PULP STORAGE
BLEACH PLANT
SCREEN ROOM
MACHINE ROOM
DIGESTER BLDG.
ACID PLANT
STRONG DIGESTER WASTES FROM SCOTT PAPER CO.
LEGEND
Existing sewers
Discontinued sewers
New sewers
② Sampling point

FIGURE 23-2. Schematic diagram of mill layout, sewer system; and sampling points; Weyerhaeuser Company sulfite pulp mill, Everett, Washington.

by heavy dashed lines. Other parts of the sewer system are shown by heavy solid lines. Survey sampling points also are shown.

Strong digester wastes and caustic extract from the bleach plant are discharged (along with strong digester wastes from the Scott mill) into Port Gardner through a deep-water diffuser. Sanitary wastes are collected and treated by the City of Everett. All other mill wastes are discharged into the near-surface waters at the entrance to Everett Harbor through three sewers (Figure 23-2).

Average results from the three surveys are listed in Table 23-3. Note that the pounds-per-ton of production loads are higher than respective loadings at the mills previously described. This is due to the significant portion of dissolving-grade pulp produced during two of the surveys; the production of dissolving pulp results in lower pulp yields and higher waste loadings. Also note that the average suspended solids loss was 6.5 tons per day. Settling tests indicated that this loss can be reduced to about 3.5 tons per day with the provision of additional sedimentation facilities.

Combined Scott-Weyerhaeuser Waste Load. Wastes from the Scott and Weyerhaeuser sulfite mills are discharged either into Port Gardner as combined wastes through the deep-water diffuser or into Everett Harbor and contiguous waters. With respect to the dispersal and water quality effects of these wastes, these two mills can be treated as a combined, single source with the two points of discharge: one at depth in Port Gardner and one in the near-surface waters of Everett Harbor. For this reason, a tabulation of combined waste loads is given in Table 23-4. Note that about 90% of the oxygen demand, sulfite waste

TABLE 23-3. Average daily waste load discharged by the Weyerhaeuser Company sulfite mill in Everett, Washington

Analyses	#/Ton of Production	Tons/Day
BOD_5	1,065	160
COD	4,704	704
SWL*	37,630	5,690
Total Sulfur	222	33.2
Total Solids	4,141	620
Volatile	3,157	468
Suspended Solids	41.6	6.7
Volatile	37.9	6.0
Supernatant Susp. Solids	21.8	3.5

Ave. Tons Production/Day (air dried)	304
Ave. % Volatile Susp. Solids Loss	2.0
Ave. Waste Volume, mgd.	26.5

* Weight of a 10% solids solution, per ton or per day as indicated.

liquor, sulfur, and total solids is discharged into Port Gardner. The waste load discharged into Everett Harbor is, primarily, suspended solids.

Simpson Lee Paper Company. This is an old mill that produces a variety of fine papers. It differs from the other mills surveyed in that it produces pulp by the sulfate (kraft) process; therefore, strong

TABLE 23-4. Combined, average daily waste load discharged by the Scott and Weyerhaeuser sulfite mills in Everett, Washington.

Analyses	Tons/Day			Percent	
	Total	To Port Gardner	To Everett Harbor	To Port Gardner	To Everett Harbor
BOD_5	533	504	29	94.6	5.4
COD	2,323	2,178	145	93.5	6.5
SWL*	19,631	18,646	985	95.0	5.0
Total Sulfur	106	96	10	90.5	9.5
Total Solids	1,826	1,622	204	89.0	11.0
Volatile	1,556	1,426	130	91.6	8.4
Suspended Solids	31.3	7.6	23.7	24.3	75.7
Volatile	28.5	7.1	21.4	24.9	75.1
Supernatant Susp. Solids	18.2	4.9	13.3	23.8	73.0
Ave. Volume, mgd.	93.2	21.4	71.8	22.9	77.1

* Weight of a 10% solids solution per day.

digester wastes are evaporated and burned for the recovery of cooking chemicals rather than disposed to surface waters. Pulp production is about 100 tons per day and this entire production is bleached. Paper production is about 180 tons per day. Purchased pulp supplements mill production to supply this paper demand. Mechanical barking is employed, thus no water-borne barking wastes are produced.

At the time of the conference in 1962, the Simpson-Lee mill was operating a de-inking mill that processed about 40 tons per day of old magazine stock. Although never surveyed, estimates based on the common characteristics of de-inking mill wastes indicated that high BOD and suspended solids loads were generated by this facility. This de-inking process has since been discontinued, and today the de-inking plant is used to repulp from 3 to 6 tons per day of broke (the cuttings, trimmings, and other paper wastes from the paper converting operations). Salvaged fiber is returned to the paper mill. This process change has substantially reduced the mill's BOD and suspended solids discharges into the Snohomish River.

A schematic diagram of the mill layout and sewer system is shown in Figure 23-3. Sampling points also are shown. All in-plant process wastes flow to a single pump sump. At this point, from 3 to over 30% of the waste volume regularly overflows into a by-pass sewer that discharges directly into the Snohomish River. The rest of the wastes are pumped to a swamp area wherein they flow along a short, meandering channel prior to discharge into the River through a submerged sewer. This swamp area provides a few hours detention time. Sanitary wastes are collected and treated by the City of Everett.

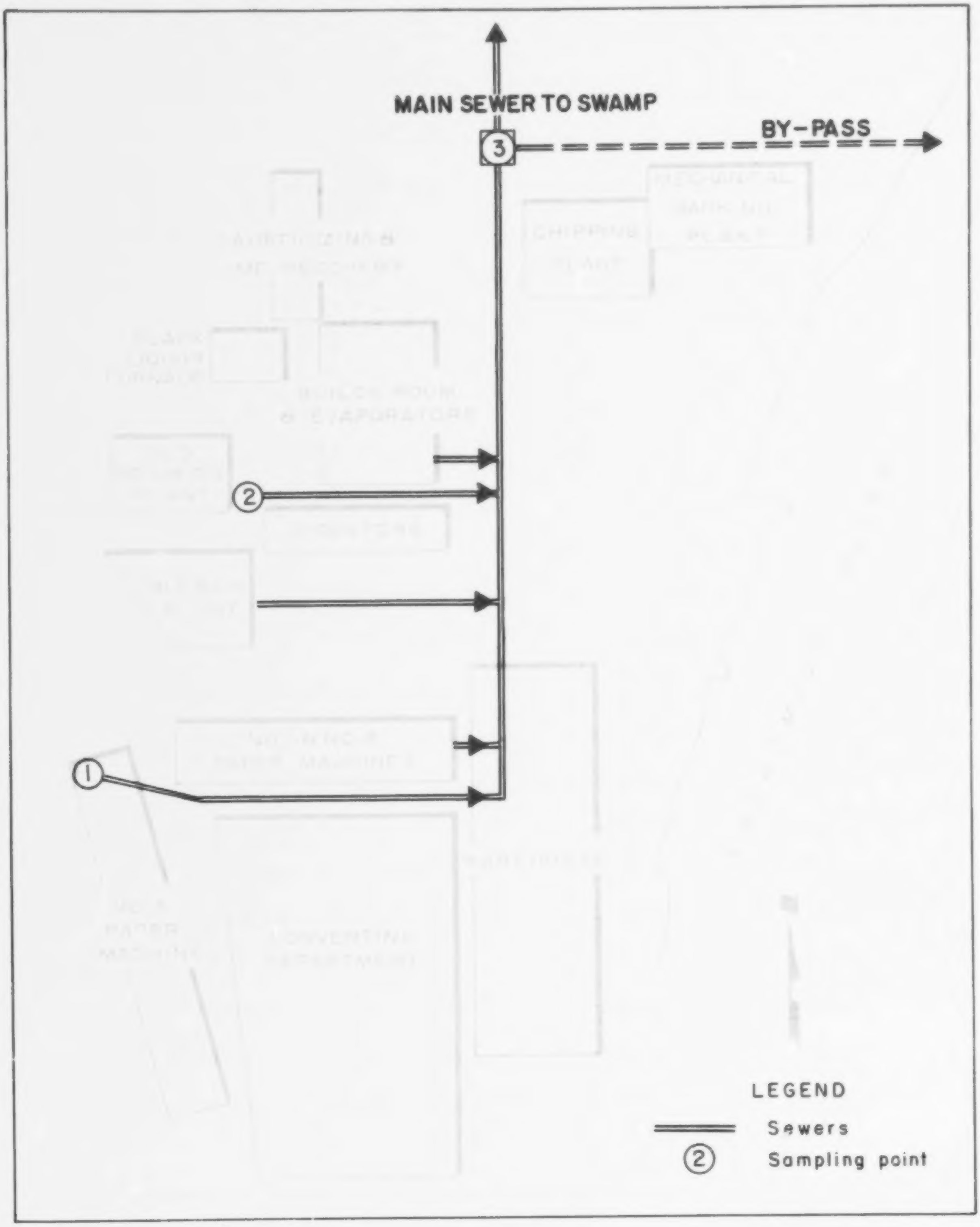

MAIN SEWER TO SWAMP
BY-PASS
3
MECHANICAL BARKING PLANT
CHIPPING PLANT
CAUSTICIZING & LIME RECOVERY
BLACK LIQUOR FURNACE
BOILER ROOM & EVAPORATORS
2
DIGESTERS
1
PAPER MACHINES
NO. 3 PAPER MACHINE
CONVERTING DEPARTMENT
WAREHOUSE
LEGEND
Sewers
2
Sampling point

FIGURE 23-3. Schematic diagram of mill layout, sewer system; and sampling points; Simpson Lee Paper Company, Everett, Washington.

Averaged results of the two surveys at this mill are tabulated in Table 23-5. Note that the pounds-per-ton-of-production values for BOD_5, COD, total sulfur, and total solids are low in comparison with respective values from the sulfite mills surveyed. These lower values result from the evaporation and burning of digester liquors for the recovery of cooking chemicals, a necessary practice in sulfate pulp production. On the other hand, note that the pounds-per-ton-of-production values for suspended solids are high compared with respective values at other mills. These result from the losses of fiber, fine-particulate clays, sizing, and other additives incorporated in the fine papers produced at this mill.

The tons-per-day loading values indicate relatively low BOD_5 and total solids discharges into the Snohomish River. Under normal river flow conditions, these loads would not have an adverse effect on water quality. On the other hand, the suspended solids discharge of 22.1 tons per day is relatively high in spite of the flotation-type save-alls on each of the paper machines. This load contributes turbidity and settleable solids to the River. Settling tests indicate that it can be reduced to about 5 tons per day by provision of adequate sedimentation facilities.

Everett Stabilization Pond. This facility--two ponds in series--treats City of Everett domestic wastes. It serves a connected population of about 50,000. Effluent is discharged into the Snohomish River (see Figure 22-1).

A 12-hour composite sample of effluent was collected between 6:00 a.m. and 6:00 p.m. Results, as interpolated for a 24-hour day, are tabulated in Table 23-6.

TABLE 23-5. Average daily waste load discharged by the Simpson Lee Paper Company at Everett, Washington

Analyses	#/Ton of Production	Tons/Day
BOD_5	46	6
COD	119	16
Total Sulfur	6	0.9
Total Solids	367	49
Volatile	134	18
Suspended Solids	166.2	22.1
Volatile	66.2	8.8
Supernatant Susp. Solids	36.3	4.8

Ave. Tons Production/Day (pulp + paper, air dried)	271
Ave. % Volatile Susp. Solids Loss	3.3
Ave. Waste Volume, mgd.	10.1

Weyerhaeuser Lumber Mills. These two mills, located on the Snohomish River (see Figure 22-1), generate liquid wastes in their debarking operation. These are given primary treatment in mechanically-cleaned clarifiers and effluents are discharged into the River. Normally, the barkers operate 16 hours each day.

At each mill an 8-hour composite sample of clarified effluent was collected. Combined results for both mills, as interpolated for 16-hours daily operation, are given in Table 23-6.

TABLE 23-6. Average daily waste loads discharged by other major waste sources in the Everett area (in tons per day).

Analyses	Everett Stabilization Pond	Weyerhaeuser Lumber Mills	Weyerhaeuser Kraft Mill	
			Sweet Sewer	Lagoon Effluent
BOD_5	0.2	1.0	0.1	19.8
COD	--	--	0.2	71.0
Apparent SWL*	0.2	2.1	0.2	455.0
Total Solids	1.4	3.6	1.1	227.5
Volatile	0.5	1.3	0.5	55.0
Suspended Solids	0.7	1.3	0.4	3.5
Volatile	0.1	0.6	0.3	2.8
Supernatant Susp. Solids	--	--	0.3	3.5
Waste volume, mgd.	1.4	1.6	3.2	23.8

* From non-sulfite-pulping constituents which give an apparent-SWL indication in the Pearl-Benson test--equivalent to tons of a 10% solids SWL solution per day.

Weyerhaeuser Company Kraft Mill. This mill (see Figure 22-1 for location) produces about 417 tons per day of bleached sulfate pulp. No paper is produced. Process wastes are discharged at two points; pulp-drying-machine wastes, which carry some suspended solids, are discharged via the "sweet sewer" into the Snohomish River; and all other wastes, including condensate wastes from kraft liquor recovery, are pumped into a large holding lagoon. Lagoon effluent is discharged into Steamboat Slough over a 5-hour period on each ebbing tide.

Three, 24-hour composite samples of sweet sewer wastes and lagoon effluent were collected by automatic samplers. Averaged results for each of these discharges are tabulated in Table 23-6.

DISCUSSION

Wastes flows into the receiving waters of the Everett area can be categorized as three discharges: (1) strong pulping wastes from the Scott and Weyerhaeuser mills discharged via the deep-water diffuser into Port Gardner; (2) weak pulping and paper mill wastes from the Scott and Weyerhaeuser mills discharged into Everett Harbor; and (3) all other wastes--from the Simpson Lee mill, the Weyerhaeuser kraft and lumber mills, and the Everett stabilization pond--discharged into the Snohomish River (includes Steamboat Slough). The waste loads contributed by each of these discharges are delineated in Figure 23-4.

Strong pulping wastes discharged into Port Gardner contribute, by far, the greatest amounts of sulfite waste liquor, total solids, and oxygen demand entering the Everett waters (upper half, Figure 23-4). That these waste properties affect water quality in the broad area of the

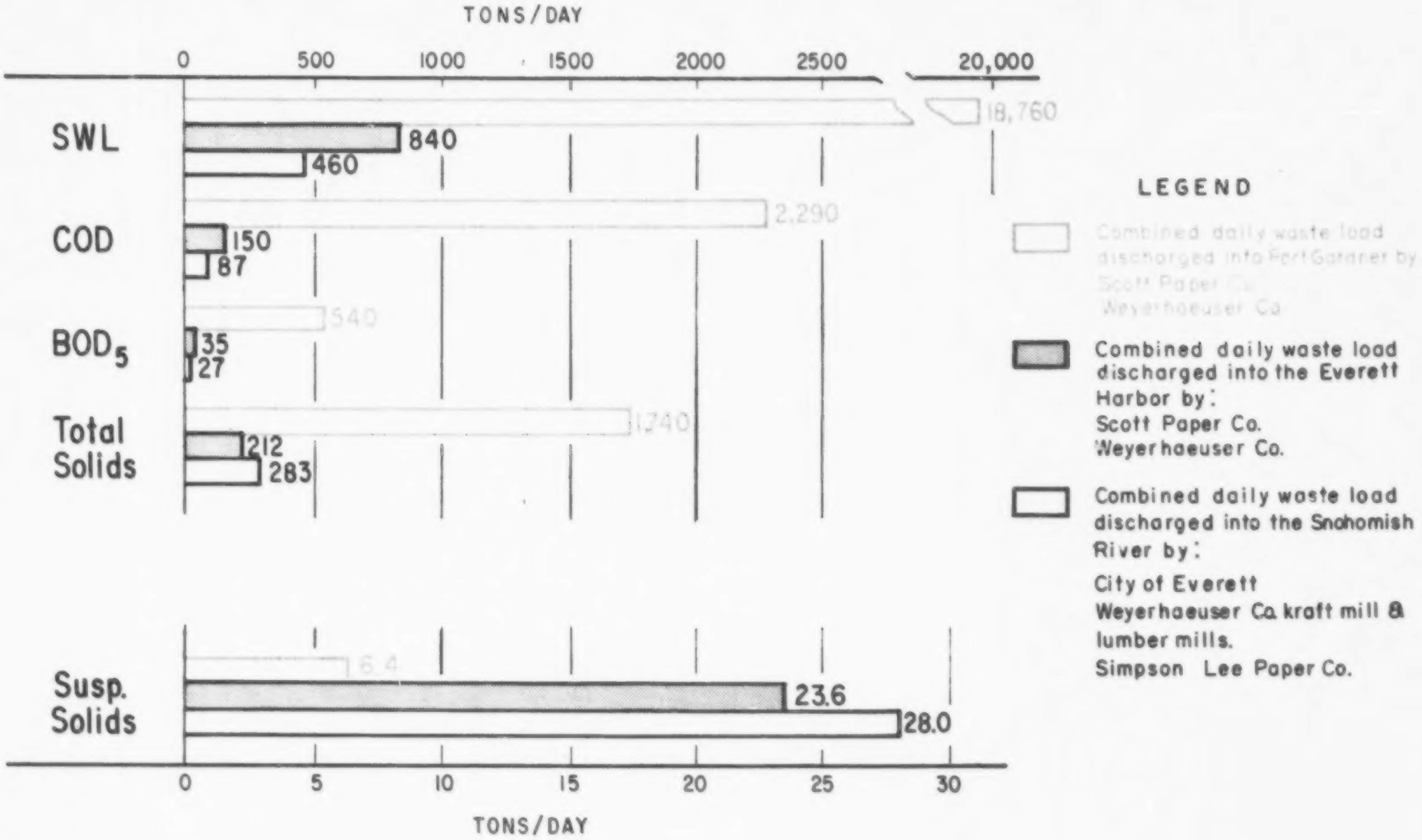


FIGURE 23-4. Comparison of total daily waste loads discharged into Port Gardner, Everett Harbor, and the Snohomish River.

Everett system is the subject of the following sections. At this point, however, it is evident that any appreciable reduction of the total SWL, COD, BOD_5, and total solids loadings presently entering the Everett waters can only be achieved through treatment or recovery of the strong sulfite waste liquors and caustic extract wastes generated in the Scott and Weyerhaeuser sulfite pulping operations.

With respect to its small size and weak circulation features, Everett Harbor also receives considerable amounts of sulfite waste liquor, total solids, and oxygen demand (Figure 23-4) from the weak pulping and paper mill wastes discharged by the same two mills. As above, to the extent that pollution abatement needs are demonstrated in the following sections, treatment or other means of disposal of these weak wastes may be required.

In the lower half of Figure 23-4, it is seen that the largest amounts of suspended solids are discharged into Everett Harbor and the Snohomish River. The Harbor receives some 24 tons of suspended solids per day from the weak pulping and paper mill wastes disposed by the Scott and Weyerhaeuser mills. Despite the solids removal provided by these two mills, settling tests have indicated this load could be reduced to about 13 tons per day through provision of additional sedimentation facilities by both mills, particularly by the Weyerhaeuser mill.

On the Snohomish River, the Simpson Lee mill is, by far, the principal source of suspended solids; it contributes some 22 tons per day. Settling tests indicate that adequate primary treatment of this mill's total waste stream would reduce this load to about 5 tons per day and, thereby, would significantly reduce the suspended solids now entering the River.

24. WASTE DISTRIBUTION AND WATER QUALITY

STUDIES

The Project conducted oceanographic and related studies in the Everett study area for the purpose of describing the distribution of wastes and waste solids discharged by the Simpson Lee, Scott, and Weyerhaeuser mills and determining the effects that these wastes have on water quality and bottom sediments. Other agencies and institutions conducted independent studies, and, where appropriate, results from these were used with Project data.

Circulation Studies. The Washington State Pollution Control Commission (Wagner, Livingston, and Ice; unpublished) conducted a float study over the deep-water diffuser during August 22-25, 1958. Floats were released at various depths down to 68 feet, and their movements were followed to determine the magnitude and direction of currents over the diffuser. Float releases were made during both flood and ebb tides.

The Weyerhaeuser Company conducted several float studies near the entrance to Everett Harbor during 1962-64. These were part of their investigations to select possible locations for a submerged outfall sewer to carry those mill wastes (weak pulping and bleach wastes) presently discharged into surface waters near the mill. Floats were released at various locations and at various depths down to 100 feet during both flood and ebb tides.

The Project conducted two fluorescent tracer studies in the Everett area. Rhodamine-B dye was used in both cases. On July 15, 1964, dye was released at the surface in a line across the Snohomish River at the highway bridge. At the same time, mimeograph paper was distributed on the water surface in a line across the entrance to Everett Harbor. The patterns of movement of both the dye and floating paper were recorded by time-lapse photography from a helicopter. During July 21-23, 1964, in cooperation with the Weyerhaeuser Company, dye studies were conducted in Port Gardner near the entrance to Everett Harbor. These were another part of the Weyerhaeuser outfall location investigations mentioned above. Dye was released at various locations and depths, and its subsequent movement was continuously monitored from the R/V HAROLD W. STREETER using a submersible pump and a Turner, Model 111, fluorometer equipped with a flow-through door.

An hydraulic model study of general circulation patterns in the Everett area was conducted by the Project in November-December 1964. The Puget Sound model at the University of Washington was used. This model has model-to-prototype scale ratios of 1:1,152; 1:40,000; and 1:1,178 for the vertical, horizontal, and time dimensions, respectively, and its operation allows for control of salinity, tides, and tributary freshwater discharges. A description of this model and its operational characteristics is given by Rattray and Lincoln (1955) and a discussion of its verifications of tidal characteristics and salinity distribution is given by Farmer and Rattray (1963). Conditions of mean ocean salinity, mean ocean tide, and mean tributary discharge were modeled for the

Project study. Discrete injections of density-adjusted, methyl-blue dye were made at 3-second intervals (about 1 hour prototype time) over a complete tidal cycle at each injection point. Injection points were located at prototype depths of 10, 50, 75, 100, and 150 meters, depth permitting, at each of the stations shown in Figure 24-1A. The movement of each dye injection was recorded by time-lapse photography at 3-second intervals.

In addition to taking direct field and model measurements of water movements and circulation, net water circulation patterns were inferred from observed distribution patterns of SWL, salinity, temperature, and dissolved oxygen, using data collected in the water quality studies.

Waste Distribution and Water Quality Studies. The Project conducted eleven oceanographic cruises in the Everett area at approximately monthly intervals between May 1962 and May 1963. Principal sampling stations were located along four transects radiating from the deep-water diffuser (Figure 24-1B). Depths sampled at each station were 0, 5, 10, 20, 30, 50, 75, 100, 125, and 150 meters, total water depth permitting. Additional stations and depths were sampled as necessary. Water properties measured were temperature, salinity, DO, SWL, and pH. Secchi-disc measurements, and wind and weather were recorded at each station occupied. In addition, a special cruise of the same type was made on November 19, 1964, during a period when a labor strike had caused the complete closure of the Scott mill and a 40% reduction in production at the Weyerhaeuser mill.

The Project also collected water quality data in each of the several biological studies conducted in the Everett area. In particular, most

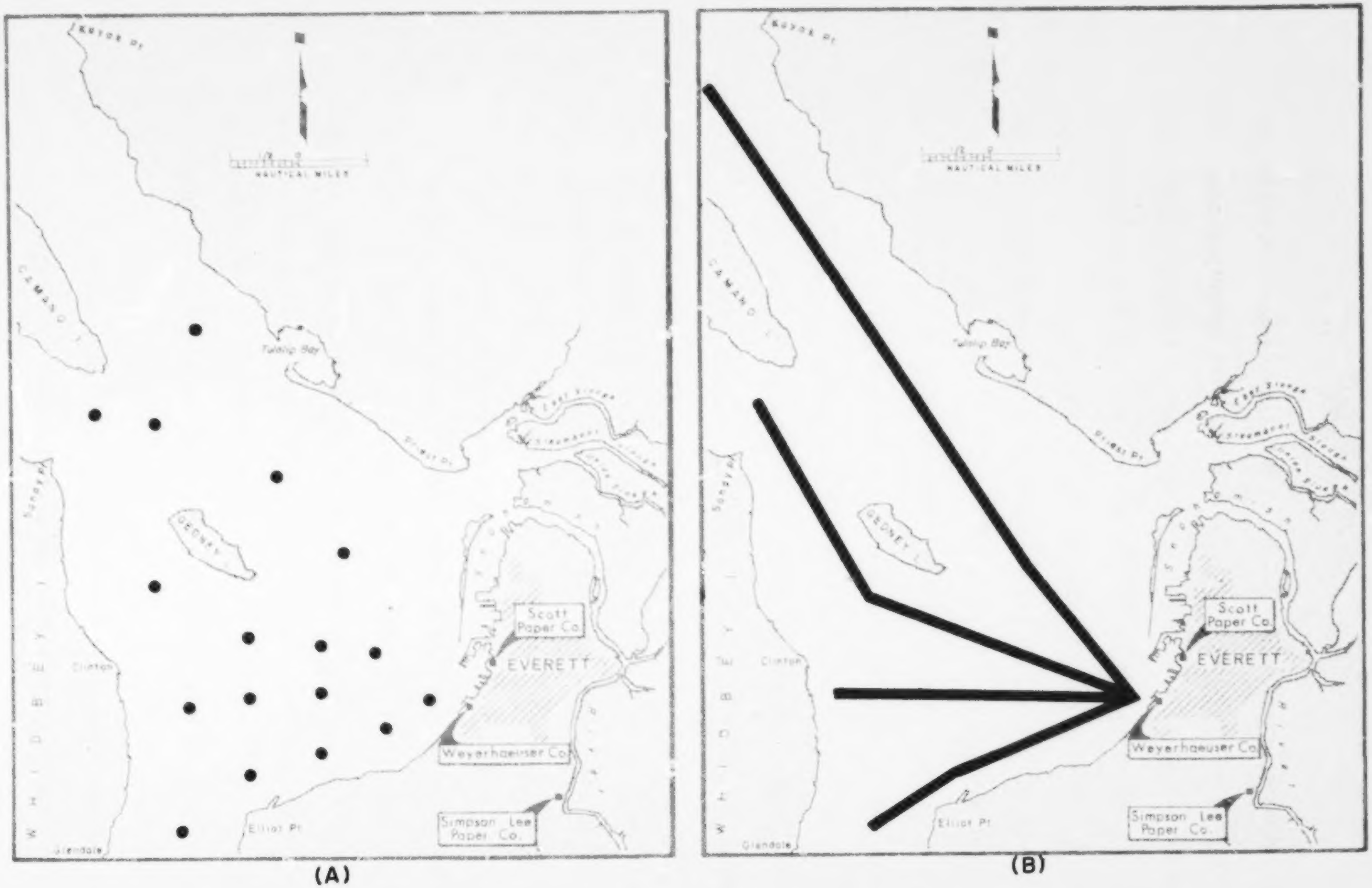

NAUTICAL MILES
Tulalip Bay
CAMANO I.
GEDNEY I.
Clinton
Glendale
Elliot Pt
Scott Paper Co.
EVERETT
Weyerhaeuser Co.
Simpson Lee Paper Co.
W H I D B E Y I.
(A)
(B)

FIGURE 24-1. (A) Dye injections points for studying water circulation in the Everett-area hydraulic model study, and (B) transects along which were located water sampling station.

of the water quality data obtained in Everett Harbor were collected in the juvenile salmon bioassay and migration studies (see Section 27). Water quality data in the Snohomish River were collected in preliminary plankton studies of 1963.

Data collection by the University of Washington and the Washington State Pollution Control Commission were examined and considered when evaluating Project results. The University's Department of Oceanography sampled, monthly, several stations in the Everett area. Water properties measured at selected depths include temperature, salinity, DO, and phosphate. Tabulated data are published regularly in the Department's Technical Report series. The Washington State Pollution Control Commission (Orlob, Peterson, and Jones; 1951) conducted a water quality study in the Everett area during June-July 1951. Measurements of DO and SWL were taken at various depths at several stations in the study area.

Bottom Deposit Studies. The Project conducted three studies in the Everett area to determine the composition of bottom sediments, and to find areas of sludge accumulation. One study was conducted during May 16-17, 1962. Samples from the top six inches of sediment were collected with a Peterson dredge at 20 stations in and near Everett Harbor (Figure 24-2A). The second study was conducted during May 22-24, 1962. Samples of the top layer of sediment were collected with a clamshell snapper at 35 stations in Port Gardner and Possession Sound (Figure 24-3A). In the third study, on September 23, 1964, sediment samples were collected with a Peterson dredge at 16 stations in the Snohomish River (Figure 24-2B). Samples from all three studies

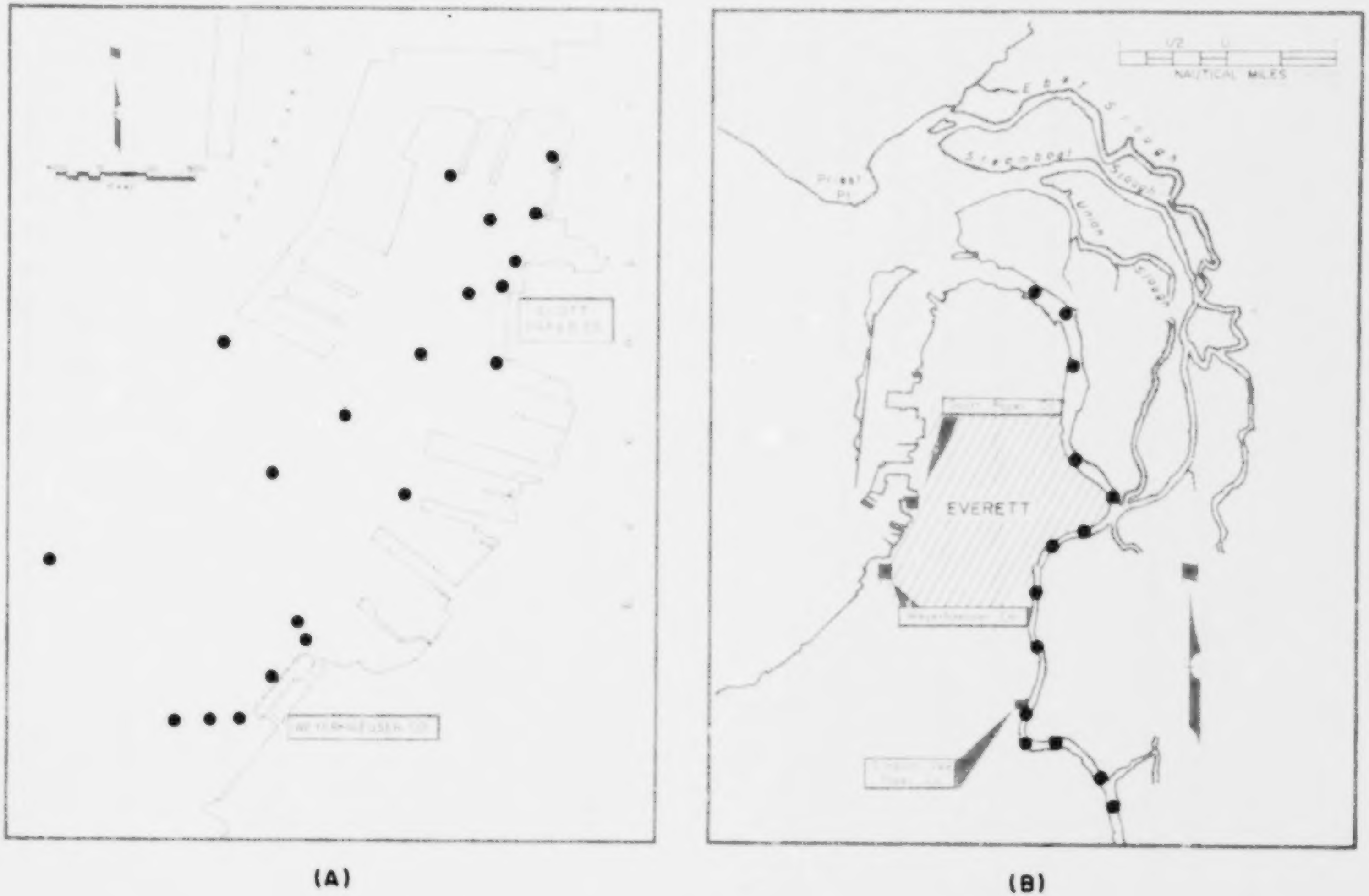

(A)
WEYERHAEUSER CO.
(B)
1/2
1
NAUTICAL MILES
Ebey Slough
Steamboat Slough
Union Slough
Priest Pt.
EVERETT

FIGURE 24-2. Bottom sediment sampling station (A) in and near Everett Harbor on May 16-17, 1962, and (B) in the Snohomish River on September 23, 1964.

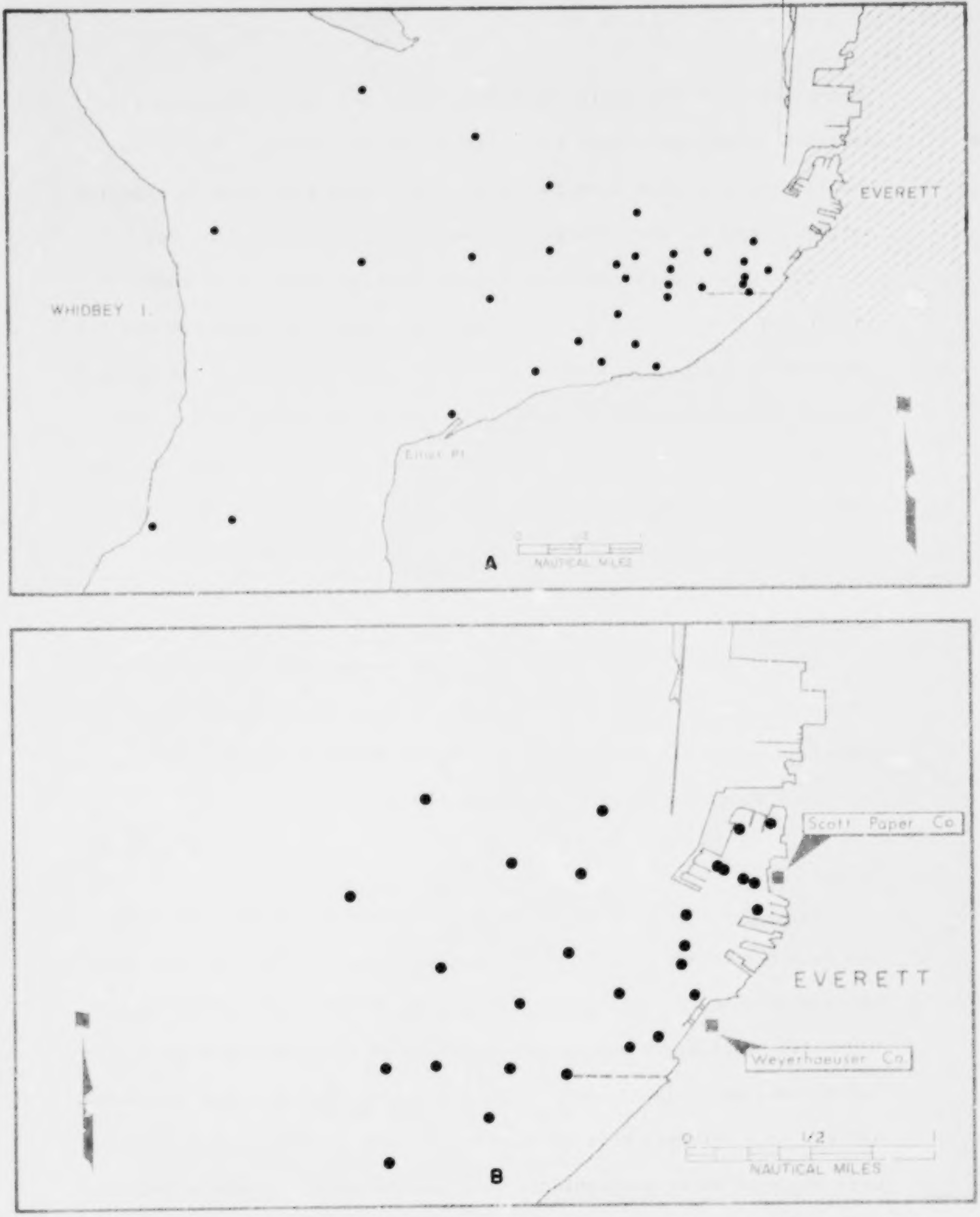

EVERETT
WHIDBEY I.
Elliot Pt
0
1
NAUTICAL MILES
A
Scott Paper Co
EVERETT
Weyerhaeuser Co
0
1/2
NAUTICAL MILES
B

FIGURE 24-3. (A) Bottom sediment sampling stations in Port Gardner and Possession Sound, May 22-24, 1962; and (B) core-sample stations in Everett Harbor and Port Gardner, March 13, 1963.

were examined in the field for color, odor, and composition and were analyzed in the laboratory for volatile solids content. These same samples (except those from the third study) were processed to separate benthic organisms for biological identification (see Section 26).

The Project also conducted a core-sampling study in Everett Harbor and Port Gardner to obtain information on the thickness and areal extent of sludge deposits. Samples were collected at 28 stations (Figure 24-3B) on March 13, 1963. A gravity coring apparatus, that collects a sample 2 inches in diameter and up to 6 feet long, was used. Samples were examined in the field for description of sediment texture, color, and odor, and measurement of sludge layer thickness.

METHODS

Field and analytical procedures used in the waste distribution and water quality studies were similar to those described in Section 7. Methods used in the circulation and bottom sediment studies were those described above and in the references cited.

RESULTS

Tidal Currents. Tidal currents in Possession Sound, Port Susan, and Saratoga Passage are described by U.S.C.&G.S. (1966) as "too weak and variable to be predicted." These same features were noted in the hydraulic model study and in occasional drift observations made during water sampling cruises. Generally, flood tide currents move northward and ebb tide currents move southward. In Port Gardner, tidal currents were observed to be particularly weak and variable. Floats released in the Port showed no strong patterns of flood or ebb motion.

Commercial fishermen in the area report that, in the absence of wind, gill nets laid out in the evening are usually in the same area the next morning. Consequently, tidal currents in the Everett area do not effect rapid dispersion and transport of discharged wastes as occurs in Guemes Channel in the Anacortes area (see Section 19).

Net Circulation. Net circulation patterns observed in the hydraulic model studies are shown for the 30-, 165-, and 330-foot depths in Figure 24-4. These results describe a three-layer net-circulation system:

1. In the surface layer of water, net motion is generally southward (Figure 24-4A).
2. At mid-depth, net motion is generally northward (Figure 24-4B).
3. In the bottom layer, net motion is, again, generally southward (Figure 24-4C).

This three-layer system is quite pronounced in Possession Sound. In Port Gardner, however, the system weakens; a distinct net motion is observed in the surface layer, but much weaker net motions are seen in the mid-depth and bottom layers.

The consequence of this three-layer circulation system is the differential dispersion of pulp and paper mill wastes in the study area. Generally, wastes discharged near the surface into Everett Harbor tend to be moved southward through Port Gardner and into Possession Sound. Wastes discharged at depth in Port Gardner tend, initially, to spread in all directions throughout the Port (there being no strong circulation patterns at depth) and, eventually, to

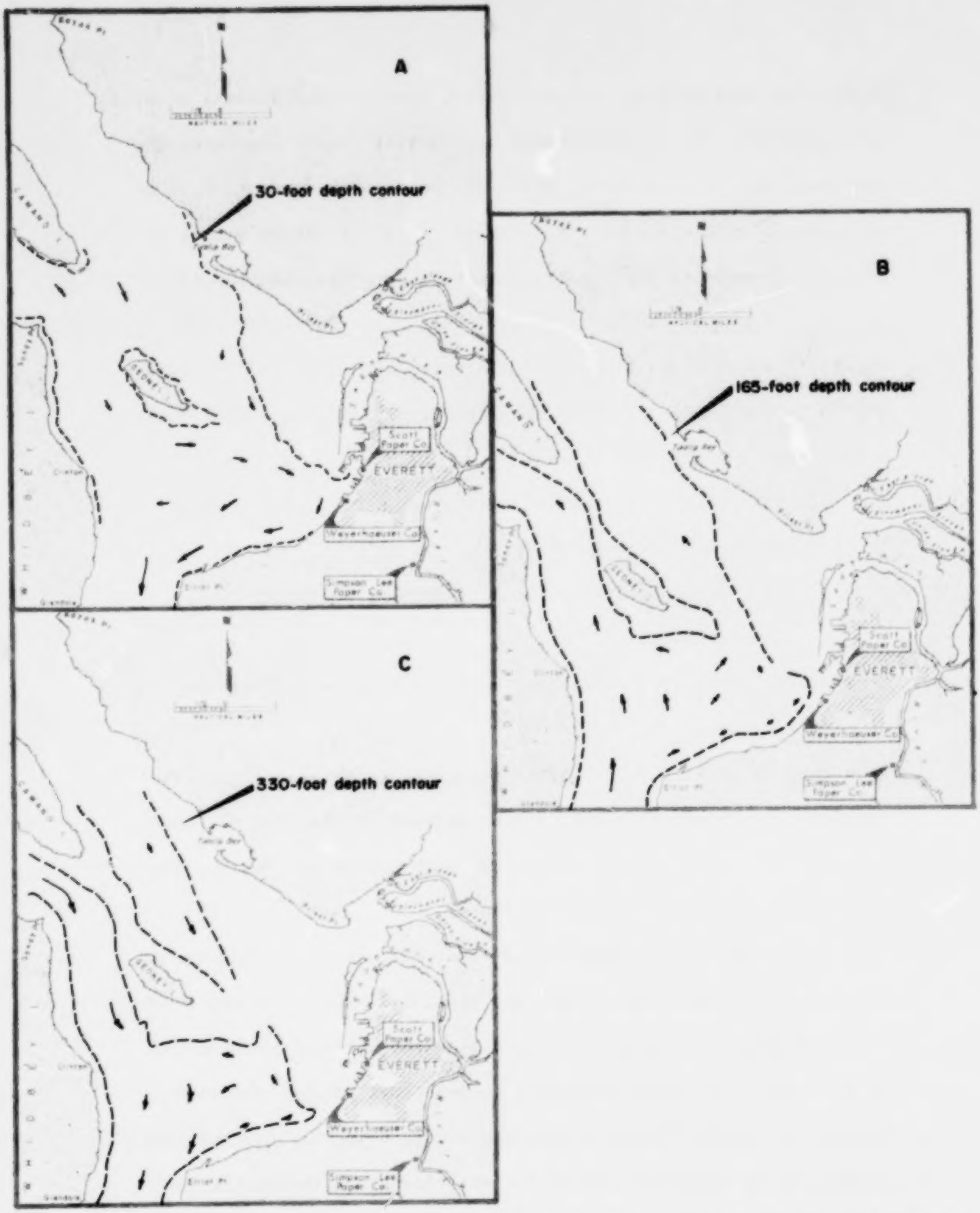

A
30-foot depth contour
B
165-foot depth contour
C
330-foot depth contour
Scott Paper Co.
EVERETT
Weyerhaeuser Co.
Simpson Lee Paper Co.
NAUTICAL MILES
Tulalip Bay
Gedney I.
Camano I.
Clinton
Elliot Pt.
Glendale

FIGURE 24-4. Patterns of net circulation at (A) 30 feet, (B) 165 feet, and (C) 330 feet in the Everett area; data from hydraulic model study.

move either northward into Saratoga Passage and Port Susan, if at mid-depth, or southward into Possession Sound, if in the bottom layer.

Surface Layer. Freshwater is discharged into the Everett area from the Snohomish River, the Stillaguamish River (into Port Susan), and the Skagit River (into Skagit Bay-Saratoga Passage). Resulting is a surface layer of less-dense water overlying more-dense saline water. In those parts of the study area receiving these discharges--including Everett Harbor and contiguous waters at the mouth of the Snohomish River--this surface layer is quite stable; *i.e.*, density stratification inhibits vertical mixing of the surface water with underlying saline water. Therefore, wastes discharged into the near-surface waters of Everett Harbor are confined in vertical distribution within the surface layer, and lateral transport of these wastes follows that of the freshwater. As already described, this lateral transport is generally southward, since all entering freshwater must flow toward the sea.

Flushing of Port Susan. Port Susan is a semi-closed body of water opened only at its southern end over sills on either side of Gedney Island (see Section 22). Because of these geomorphic features, the Port is not afforded continuous tidal flushing such as occurs in the more-open waters of Port Gardner and Possession Sound. Instead, net circulation consists of (1) inflowing saline water from Port Gardner entering at mid-depth and moving very slowly northward, and (2) outflowing less-saline water (originating from Stillaguamish River discharges) on the surface. Net current velocities are very low;

therefore, flushing--the periodic renewal of water--is a long-term situation. Consequently, pulp and paper mill wastes carried into Port Susan in the inflows of water from Port Gardner have a long residence time in the Port and are afforded very little additional dilution because of weak mixing.

Annual flushing of Port Susan is provided, however, by upwelling ocean water entering the study area. Cold, highly-saline, low-oxygenated water, upwelled in the Pacific Ocean along the Washington coast during the spring and summer, enters and slowly spreads at depth throughout Puget Sound, reaching the Everett area in the late summer or fall. This influx of dense water enters Port Susan and moves northward along the bottom. It displaces the existing water mass upwards and causes it to be flushed out of the Port on the surface. Thereby, the water mass of the Port is annually renewed and long-resident wastes are purged from the system.

Vertical Waste Distribution. Vertical waste distribution is illustrated in Figure 24-5. Shown are the patterns of average SWL concentration in the vertical sections along the four sampling transects. These are derived from results of the Project's 11 oceanographic cruises.

Evident is the separation between the distribution of wastes in the surface layer and the distribution of wastes at depth. This separation occurs in the depth region of 15-35 feet, and it is the result of density stratification inhibiting vertical mixing of surface waters with underlying, more-saline waters. Wastes discharged into the near-surface waters of Everett Harbor (weak pulping and paper mill

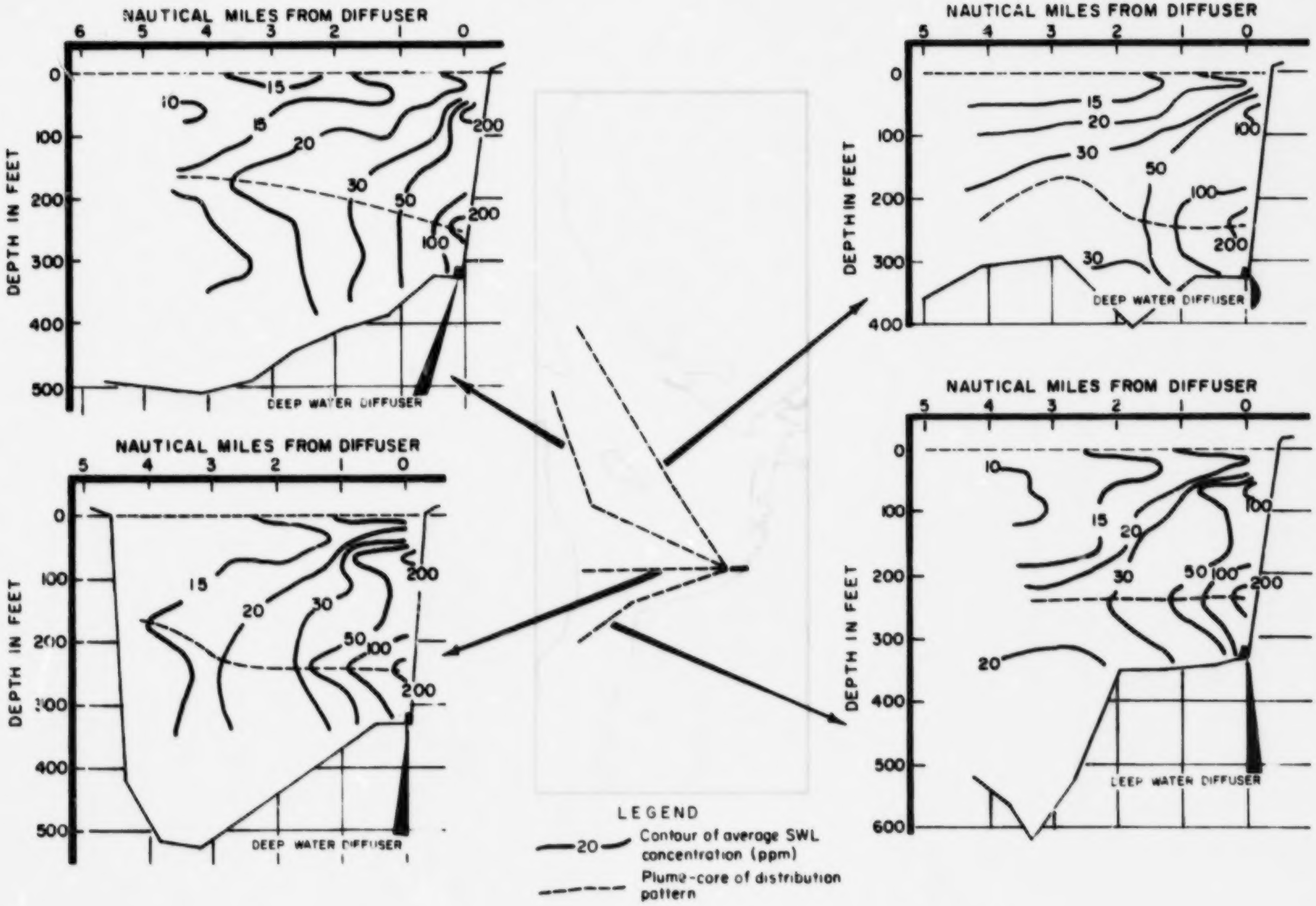


FIGURE 24-5. Vertical distribution of average SWL values taken along the four sampling transects in the Everett area, May 1962 to May 1963.

wastes) are shown spread in a surface lens extending 2-4 miles out from the Harbor. Wastes disposed at depth in Port Gardner (strong pulping wastes) are seen distributed both vertically and horizontally throughout the bottom waters. In the far regions of the system, 4-5 miles from the Harbor and diffuser, separation between the surface and deep-water distribution patterns weakens due to dilution of the wastes from both sources and to gradual mixing of the surface and underlying waters. Accordingly, wastes concentrations in these far regions derive from both Everett Harbor and deep-water diffuser wastes.

Wastes discharged by the deep-water diffuser are less dense than the receiving waters of Port Gardner; hence, they are subject to an initial buoyant rising. Jet mixing at the diffuser and turbulence during the rise dilute the waste mass with environing saline water and, thereby, reduce its density differential. Eventually, density-equilibrium with surrounding waters is reached and initial buoyant rising ceases--in this case, at about the 250-foot depth (see the 200 ppm SWL contour, Figure 24-5). From this point, the wastes are transported and dispersed by the water currents and turbulence of the Everett system. Of significance, discharge-strength diffuser waste concentrations are confined to the deep waters of Port Gardner.

After the initial rising, considerable lateral transport and dispersion with accompanying vertical dispersion take place. This is shown by the plumed configurations of the distribution patterns shown in Figure 24-5. The main body of wastes--depicted by the dashed lines--continues to rise slowly, but this rise is arrested at about the 150-foot depth. Consequently, maximum concentrations of the dispersed wastes continue to be confined to the deep water of the system.

The small plume of wastes noted at the 75-foot depth (Figure 24-5) resulted from waste discharges through a break in the deep-water diffuser line during the survey period. This break has since been repaired, and the subject anomaly no longer exists.

Horizontal Waste Distribution. Horizontal waste distribution in the surface layer is shown in Figure 24-6 by patterns of SWL concentration at the 0-, 15-, and 30-foot depths. Similarly, horizontal distribution at depth is shown in Figure 24-7 by SWL patterns at the 100-, 165-, and 330-foot depths. These patterns are derived from results of the Project's 11 oceanographic cruises.

Most prominent is the broad spreading of wastes at all depths throughout the Everett system. Generally, in conformance with net circulation features previously described, there tends to be greater southward transport of wastes near the surface (Figure 24-6) and near the bottom (Figure 24-7C) and greater northward transport of wastes at mid-depth (Figure 24-7A & B). This latter transport serves to carry wastes into Port Susan (particularly notable in Figure 24-7B) and into Saratoga Passage.

Water Quality - Port Gardner and Contiguous Waters. In the broad areas of the Everett system--excluding Everett Harbor--the most important effect on water quality caused by waste discharges of the Scott and Weyerhaeuser mills is the spreading of pulping wastes. Minimum observed SWL concentrations are greater than background values (0-2 ppm) at almost all points in the study area. Highest waste

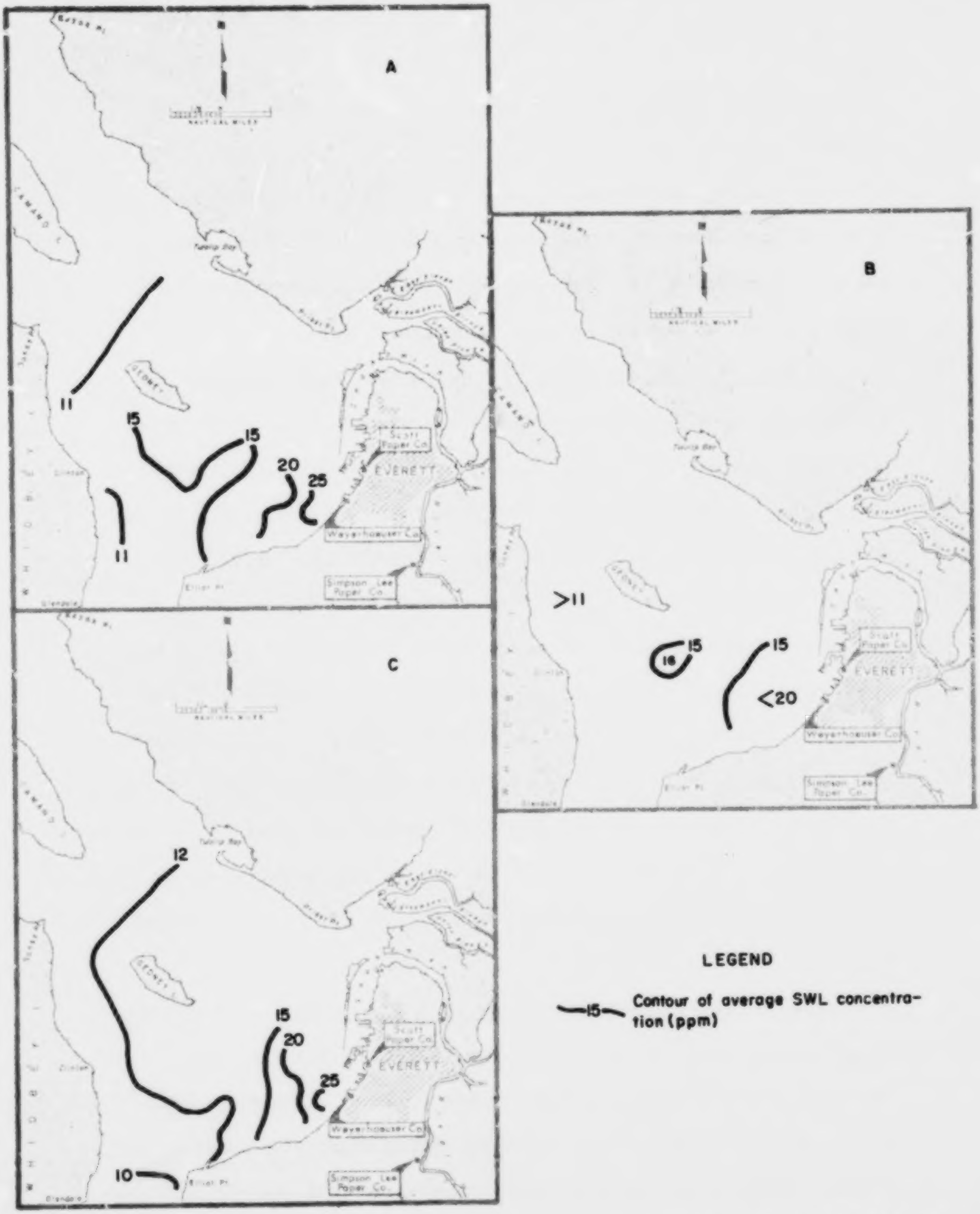

A
11
11
15
15
20
25
Scott Paper Co.
EVERETT
Weyerhaeuser Co.
Simpson Lee Paper Co.
B
>11
16
15
15
<20
C
12
15
20
25
10
LEGEND
—15— Contour of average SWL concentration (ppm)

FIGURE 24-6. Horizontal distribution of average SWL concentrations (A) at surface, (B) at 15-foot depth, and (C) at 30-foot depth in the Everett area, May 1962 to May 1963.

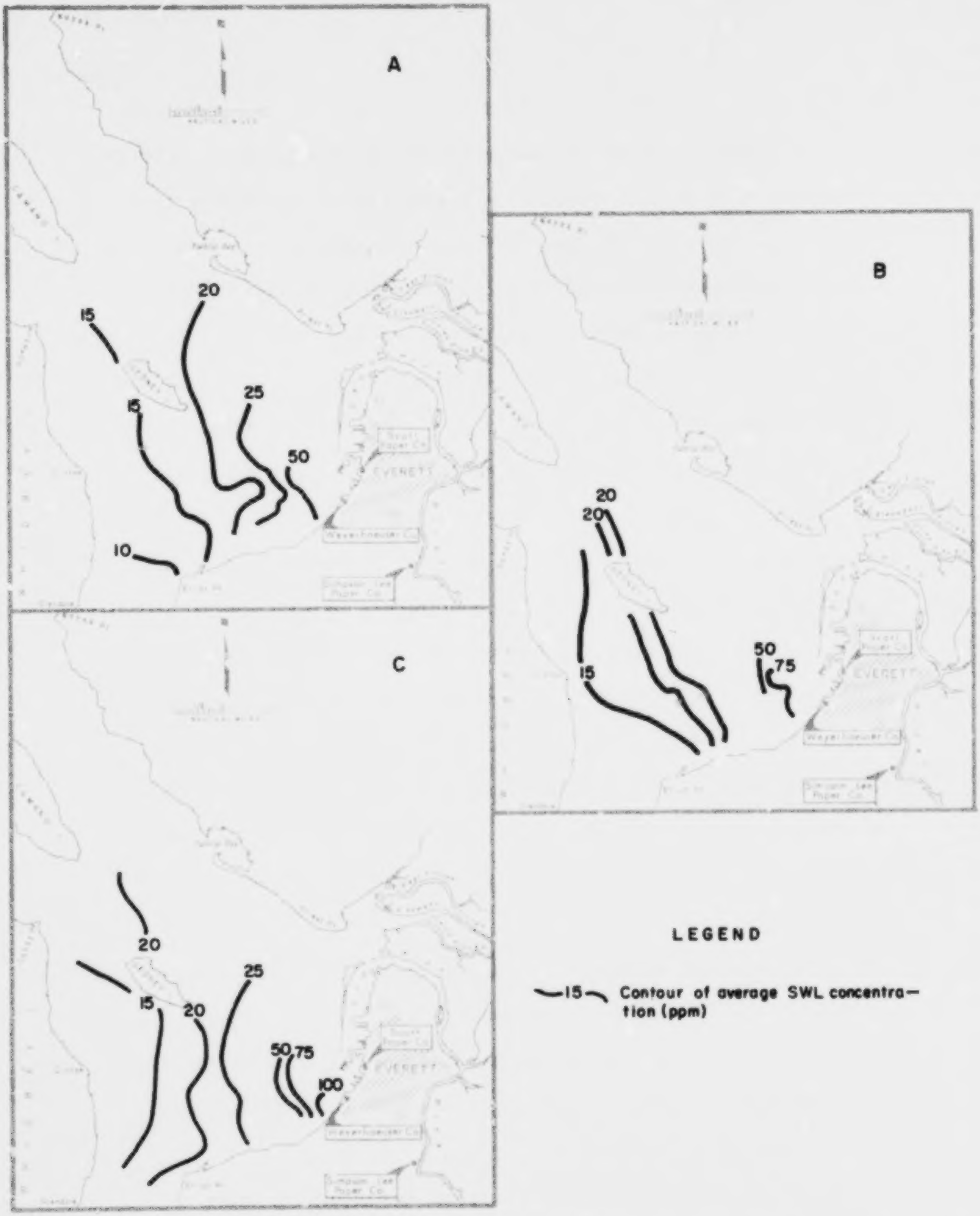

A
15
20
15
25
50
10
Scott Paper Co.
EVERETT
Weyerhaeuser Co.
Simpson Lee Paper Co.
B
20
20
15
50
75
Scott Paper Co.
EVERETT
Weyerhaeuser Co.
Simpson Lee Paper Co.
C
20
15
20
25
50
75
100
Scott Paper Co.
EVERETT
Weyerhaeuser Co.
Simpson Lee Paper Co.
LEGEND
15 Contour of average SWL concentration (ppm)

FIGURE 24-7. Horizontal distribution of average SWL concentrations (A) at 100-foot depth, (B) at 165-foot depth, and (C) at 330-foot depth in the Everett area; May 1962 to May 1963.

concentrations are found below the 150-foot depth and, as previously described, derive from the discharge of strong pulping wastes through the deep-water diffuser. Generally, throughout the central portion of the study area (Port Gardner, the southern part of Port Susan, and contiguous parts of Possession Sound and Saratoga Passage) average SWL concentrations at depth exceed 15 ppm and reach 250 ppm near the diffuser (Figures 24-5 and 24-7). Maximum SWL concentrations at depth in this central region range from 25 to 750 ppm (Figure 24-8). In the surface layer (0 to 35 feet deep), discharges of weak pulping and paper mill wastes cause lesser waste concentration; average SWL values range from 10 to 25 ppm (Figures 24-5 and 24-6) and maximum SWL concentrations range from 15 to 100 ppm (Figure 24-8).

Inflowing water from Port Gardner introduces SWL concentrations of between 30 and 50 ppm into Port Susan (see Transect D, Figure 24-5). Since there is little chance for further dilution once the wastes enter Port Susan, these concentrations maintain throughout the deep waters of the Port throughout most of the year. Average SWL concentrations of about 30 ppm are found at mid-depth in the northern part of this basin.

Other measured effects on water quality in the broad areas of the Everett system include (1) reduced pH and dissolved oxygen content in the deep waters surrounding the deep-water diffuser and (2) coloration and reduced light penetration in the surface waters covering most of Port Gardner.

Harbor Circulation. For the purpose of discussing water circulation characteristics, Everett Harbor is separated into two

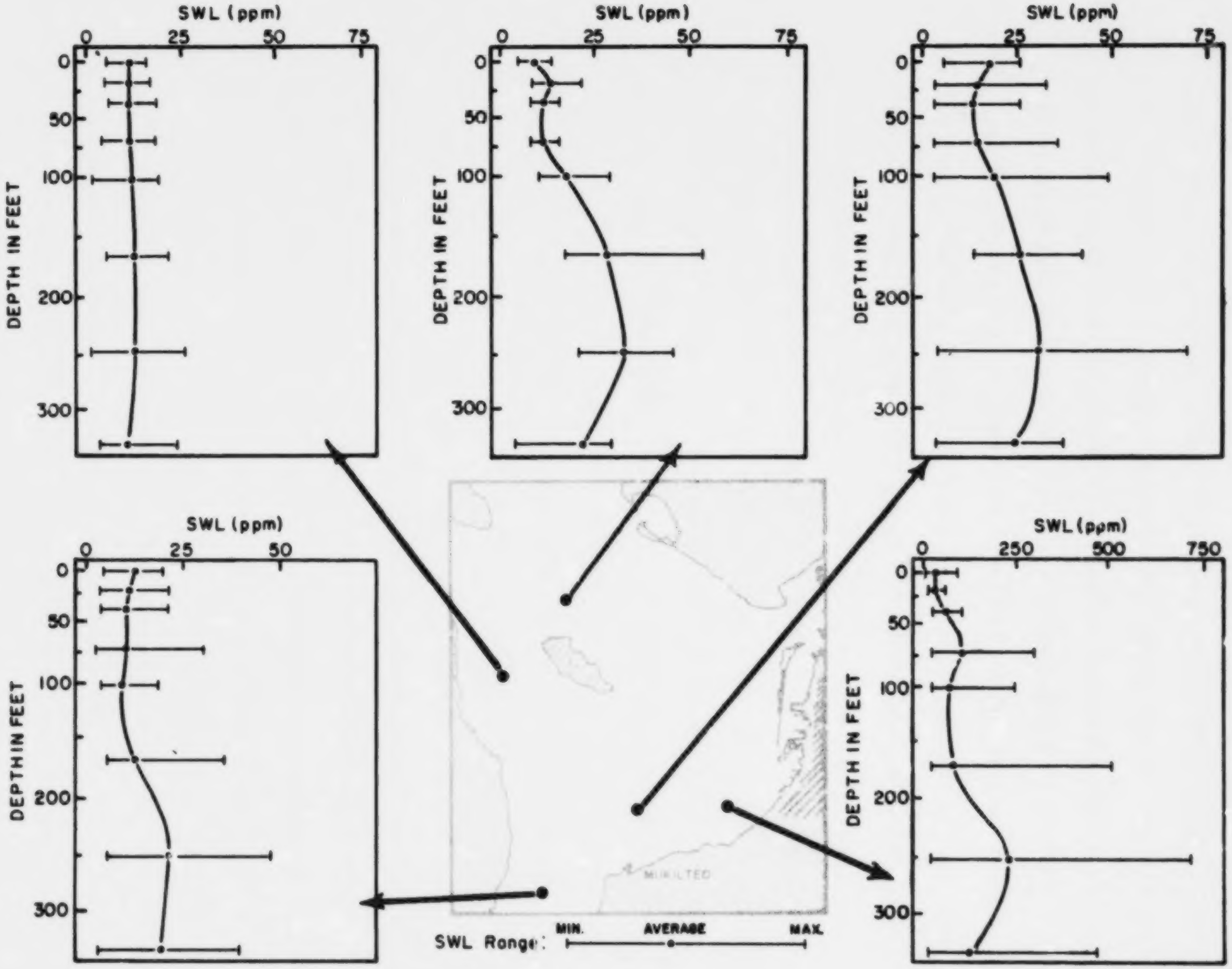


FIGURE 24-8. Vertical distribution of average, maximum, and minimum SWL concentrations at five stations in the Everett area; May 1962 to May 1963.

areas: Area A, the semi-closed inner harbor adjacent to Scott mill, and Area B, the remaining harbor waters opening to Port Gardner and adjacent to Weyerhaeuser sulfite mill (Figure 24-9). Within Area A, tidal currents are extremely weak and variable with near-stagnation apparent in some of the innermost pier areas. As a result, Scott mill wastes are only slowly dispersed throughout this area, particularly along the east dockfront. Net transport in Area A is basically two-layer; saline water from depth in Port Gardner moves inward along the bottom while fresher inflow--the 70 cfs Scott mill waste discharge--moves outward near the surface. Consequently, net movement of Scott mill wastes is out of Area A and Everett Harbor, but weak and variable short-term circulation serves to disperse the wastes throughout the Harbor before moving them into Port Gardner.

In Area B, currents are also weak and variable and are often part of eddies created by tidal currents at the mouth of Snohomish River. Thus surface-discharged wastes from Weyerhaeuser mill may be transported northward or southward into Port Gardner. Current speeds in Area B are generally less than 0.25 knot at all depths, although surface currents are considerably influenced by winds greater than 5-10 knots and, during such periods, may move faster and at a different direction than sub-surface currents. The inward net transport of saline water at depth in Area A has been observed in Area B as far as the Weyerhaeuser dock area. Because of the general circulation pattern in Area B, Weyerhaeuser mill wastes are dispersed and transported into Port Gardner more rapidly than those from the Scott mill in Area A. However, periods of slack motion do occur in

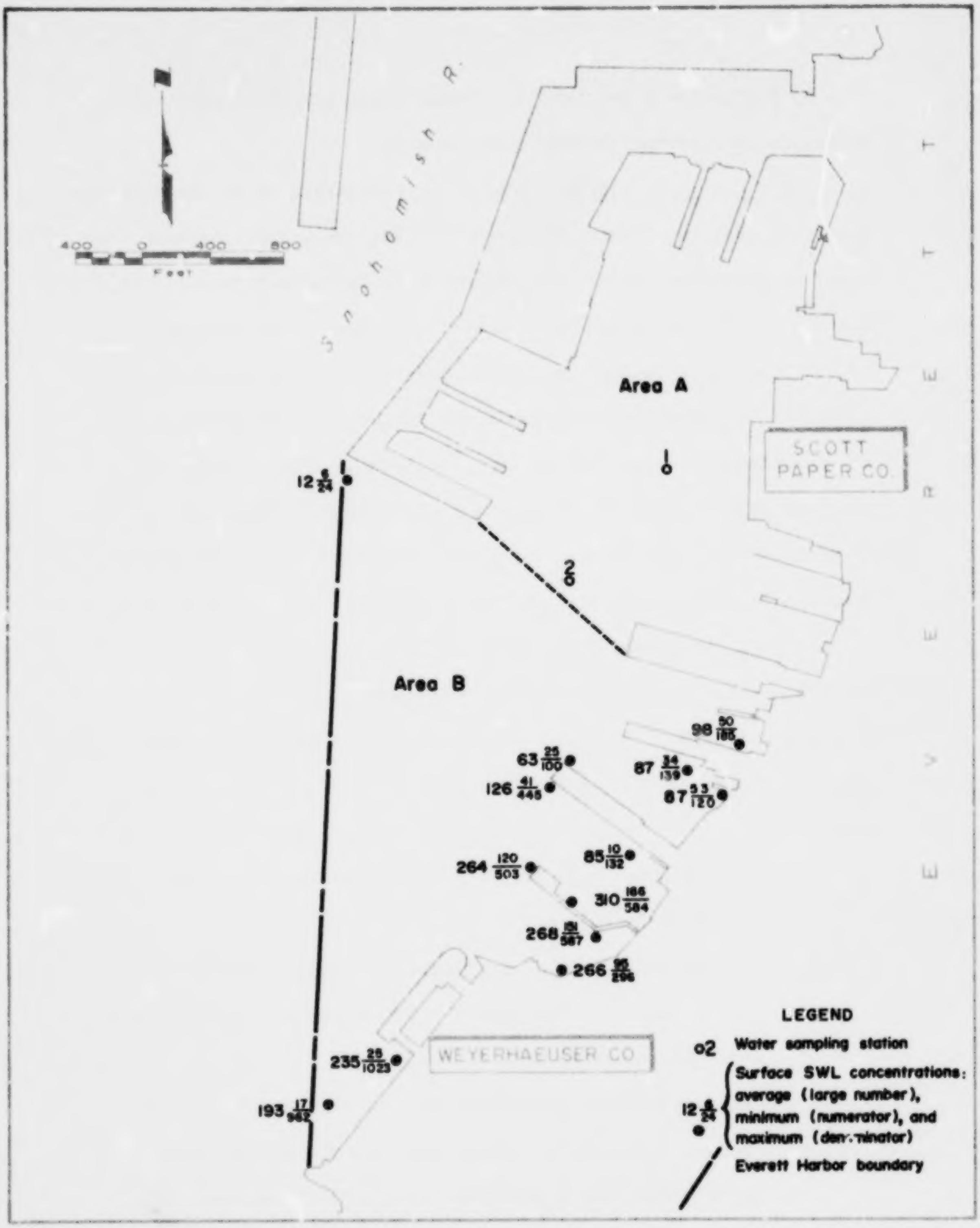

Snohomish R.
400 0 400 800
Feet
EVERETT
Area A
1
SCOTT PAPER CO.
2
Area B
12 6/24
98 50/185
63 25/100
87 34/139
126 41/445
87 53/120
85 10/132
264 120/503
310 186/584
268 151/587
266 95/296
235 25/1023
193 17/962
WEYERHAEUSER CO.
LEGEND
o2 Water sampling station
12 6/24 Surface SWL concentrations: average (large number), minimum (numerator), and maximum (denominator)
Everett Harbor boundary

FIGURE 24-9. Areas A and B of Everett Harbor; stations 1 and 2 in Area A, and surface SWL concentrations observed in Area B during juvenile salmon bioassay study of May 7-23, 1963.

Area B, particularly near the dockfront, which result in high waste concentrations around the Weyerhaeuser mill.

Water Quality - Everett Harbor. In describing waste distribution and water quality, Everett Harbor may be separated into the same two areas as described above: Area A, which is influenced by Scott mill wastes, and Area B, where water quality is largely affected by Weyerhaeuser mill wastes. All water sampling in Everett Harbor was a part of biological studies conducted therein. Total sulfides, DO, and pH values, measured during the floating-lab juvenile-salmon bioassay studies in the Harbor, are summarized in Table 25-4. Average SWL, DO, and pH values derived from the harbor station (Station 1) occupied in the plankton study are given in Table 29-1.

In September 1963, Scott Paper Company converted its method of waste discharge (into Area A) from a surface outfall to a submerged dockfront diffuser. In evaluating the effect of this changeover on water quality in Area A, a comparison of "before and after" data shows:

1. Foam problems and attendant water murkiness have been considerably reduced.
2. Maximum surface SWL concentrations near the outfall have been reduced by about half, by creation of a more uniform waste distribution with depth.
3. The distribution of average SWL concentrations has not changed appreciably, particularly in the Harbor waters which join Areas A and B and open to Port Gardner. Thus,

oceanographic data collected prior to diffuser installation, describing the distribution of Harbor wastes into the outer waters, is representative of present conditions.

4. The dissolved oxygen regime is essentially unchanged, and low DO levels, approaching zero, still occur.
5. Sulfides produced by Harbor sludge deposits are still present.

Water quality data collected at two stations (Figure 24-9) in Area A after installation of the dockfront diffuser are summarized in Table 24-1.

In Area B waste distribution and water quality are extremely variable due to the eddy-nature of the tidal currents. Concentrations of SWL range from lows of about 10 ppm adjacent to Port Gardner to highs exceeding 1,000 ppm near Weyerhaeuser mill dock. Surface SWL concentrations observed during the May 7-23, 1963 juvenile salmon bioassay study (Section 25) are summarized in Figure 24-9. Low DO values approaching zero occasionally occur in some of the pier areas.

Sludge Deposits - Everett Harbor and Port Gardner. The Scott and Weyerhaeuser mills presently discharge an average of 10.5 tons per day of settleable solids, primarily wood fibers, into Everett Harbor and its entrance waters. These mills also discharge an average of 2.3 tons of settleable solids per day into Port Gardner, through the deep-water diffuser. Weak and variable currents in these receiving waters allow the settling and deposition of these solids in the vicinity of their discharge. Consequently, sludge deposits are formed in and immediately outside of Everett Harbor.

TABLE 24-1. Summary of SWL, DO, and pH values observed in Area A of Everett Harbor after installation of the dockfront diffuser by the Scott mill; data from plankton study.

Location	Depth (ft)	SWL (ppm)			DO (mg/1)			pH		
		Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Station 1 (Aug. 1964-July 1965)	1	20	82	176	3.08	5.88	9.87	6.92	7.36	7.70
	16	29	89	201	4.26	5.62	7.39	6.80	7.34	7.85
	33	22	79	143	0	4.25	7.75	6.80	7.34	7.56
Station 2 (Sept. 1963-June 1964)	1	21	84	217	3.85	6.63	9.02	7.25	7.51	7.96
	7	22	83	168	4.17	6.67	8.78	7.11	7.46	8.00
	20	10	59	140	2.99	6.24	8.46	7.26	7.58	8.07

Other major sources of settleable solids are the wood-chip unloading facilities at the Scott mill and log storage areas in the western and northern parts of the Harbor. Unloading of chip barges with a clamshell bucket produces considerable spillage of chips into the water. Handling and moving of logs in storage tears off bark and wood particles which sink into the water. Additional, but smaller sources of settleable solids, are waste discharges from ships in the Harbor, spillage from other barge and ship loading operations, and discharges of domestic wastes and storm drainage (however, most domestic waste sewers, which previously discharged into Everett Harbor, are now intercepted and flow to the City of Everett stabilization pond).

The thickness and areal coverage of sludge deposits in Everett Harbor and Port Gardner are shown in Figure 24-10. Volatile solids content--a measure of organic content--of sludge and bottom sediments in the Everett area is shown in Figure 24-11.

Six to twenty-eight inches of sludge blanket Everett Harbor and this deposit extends into Port Gardner in a plume of sludge from four to over ten inches thick. This sludge mass contains an abundance of wood fibers, wood chips, and wood and bark fragments; and its volatile solids content ranges from 15% in the plume outside the Harbor to over 50% in the vicinity of the Scott mill. These values exceed the 5 to 9.7% volatile solids in the natural sediments of Port Gardner. Anaerobic decomposition of this sludge is evidenced by its black color and hydrogen sulfide odor. In the vicinity of the Scott mill, anaerobic conditions suffice to produce floating masses of sludge and bubbles of gas (hydrogen sulfite, methane, and carbon dioxide) which

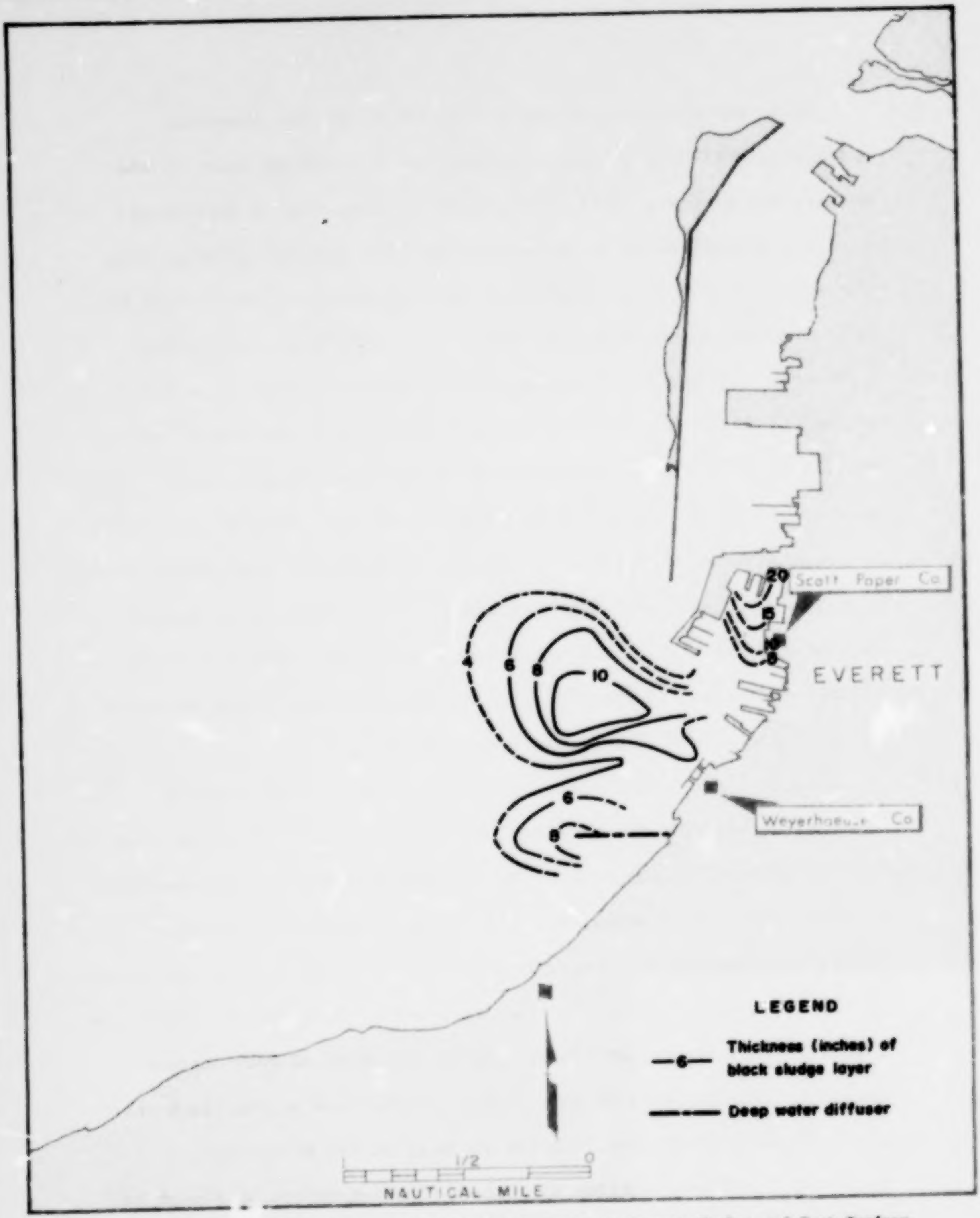

Scott Paper Co
EVERETT
Weyerhaeuser Co
20
15
10
8
4
6
8
10
6
8
LEGEND
—6— Thickness (inches) of black sludge layer
— - — Deep water diffuser
1/2
0
NAUTICAL MILE

FIGURE 24-10. Thickness and coverage of sludge deposits in Everett Harbor and Port Gardner.

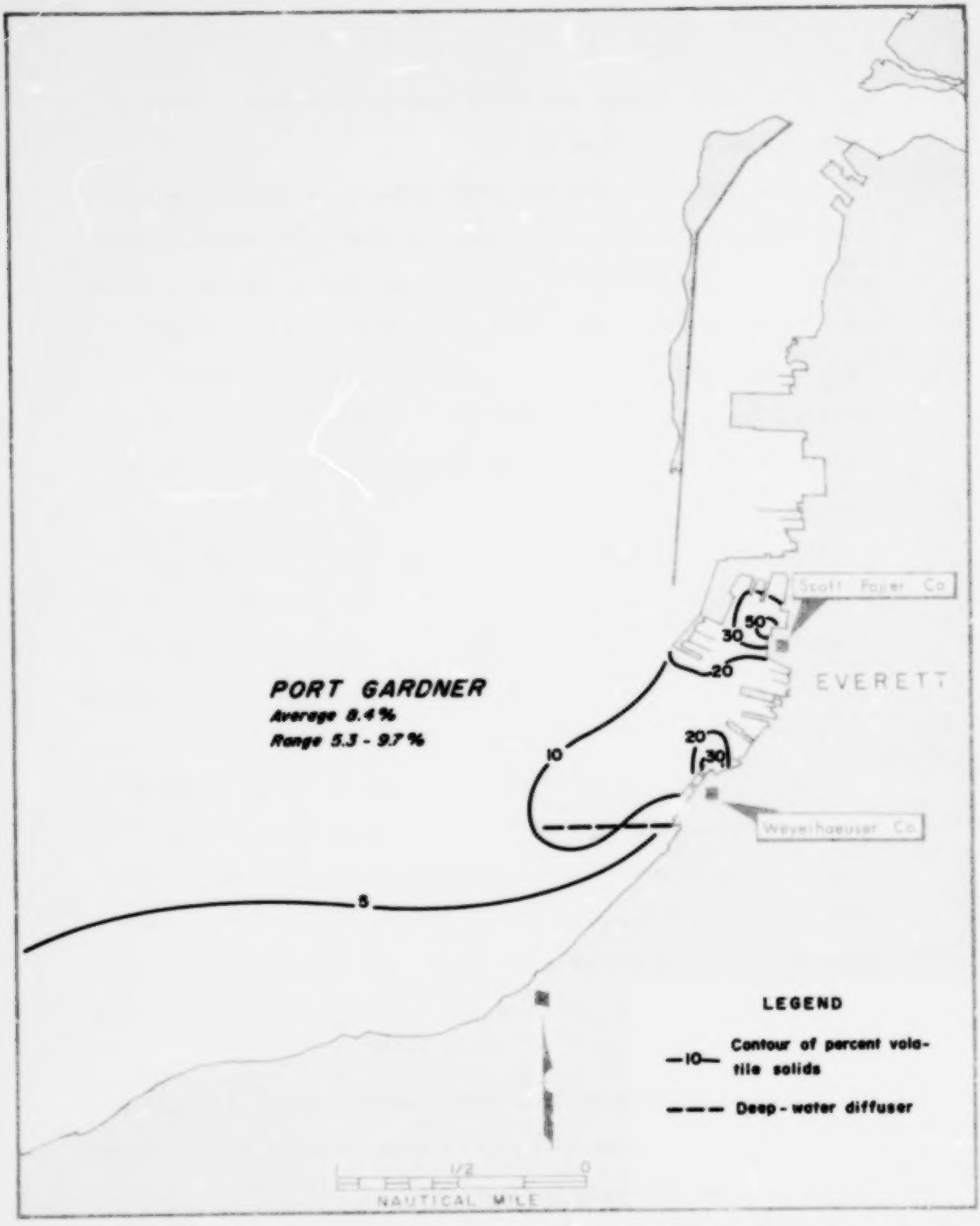

Scott Paper Co
50
30
20
EVERETT
PORT GARDNER
Average 8.4%
Range 5.3 - 9.7%
10
20
30
Weyerhaeuser Co
5
LEGEND
—10— Contour of percent volatile solids
— — — Deep-water diffuser
1/2
0
NAUTICAL MILE

FIGURE 24-11. Percent volatile solids in the sludge and bottom sediments of Everett Harbor and Port Gardner.

rise to the water surface and escape into the atmosphere. These conditions usually occur at low tides.

In the vicinity of the deep-water diffuser, a second deposit of sludge blankets the bottom. This mass contains wood fibers and some wood chips intermixed with mud and silt, the natural sediments of the area. Volatile solids exceed 10%; hence, organic content of this deposit slightly exceeds that of contiguous natural sediments. Black-to-grey color and a musty or slight hydrogen sulfite odor evidence some anaerobic decomposition of organic material in this deposit.

Elsewhere in Port Gardner and in Possession Sound, natural sediments are odorless, are olive-grey in color, and contain varying amounts of mud, silt, and sand. They are aerobic, as indicated by their color, lack of odor, and the types of inhabiting bottom organisms (see Section 26).

Water Quality - Snohomish River. Background levels of SWL in the Snohomish River range from 0 to 7 ppm and average 3 ppm. These were determined from grab samples taken periodically during 1964-65 at a point about one mile upstream from Station 1 (Figure 24-12). Since these samples were taken above major wastes discharges into the River, the results obtained are "apparent SWL" attributed to natural-drainage materials (see Section 1).

A summary of Snohomish River water quality results obtained in the plankton ecology studies of 1963 is given in Table 24-2. Sampling station locations are shown in Figure 24-12.

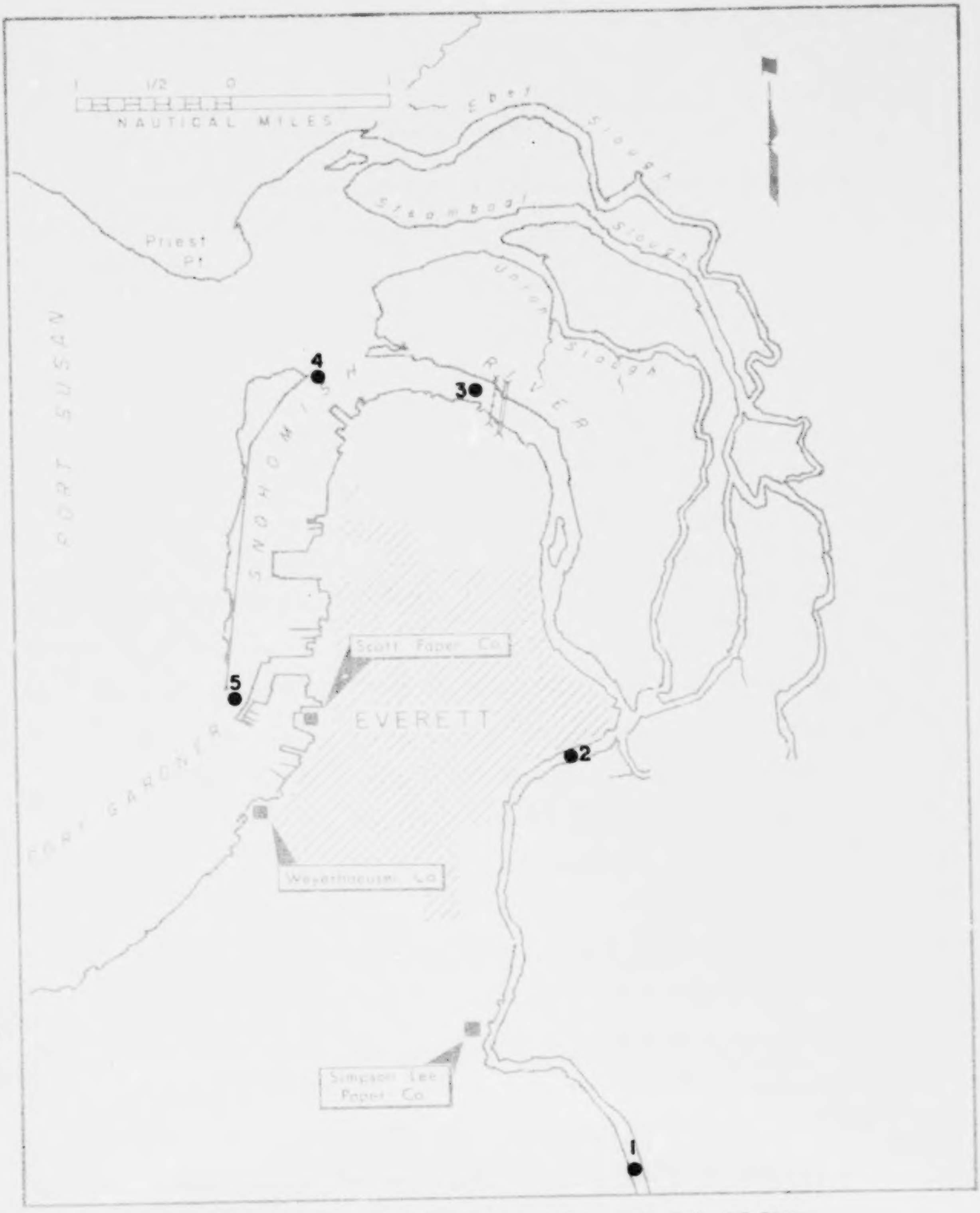

1 1/2 0 1
NAUTICAL MILES
Ebey Slough
Steamboat Slough
Union Slough
Priest Pt
PORT SUSAN
SNOHOMISH RIVER
4
3
5
2
1
Scott Paper Co.
EVERETT
PORT GARDNER
Weyerhaeuser Co.
Simpson Lee Paper Co.

FIGURE 24-12. Water quality sampling stations on the Snohomish River.

TABLE 24-2. Summary of observed concentrations of SWL and DO in the Snohomish River

	SWL*		DO		
Station	Average at Low Tides (ppm)	Average at High Tides (ppm)	Average (ppm)	Minimum (ppm)	Less than 5 ppm (%)
1	4	--	10.5	9.1	0
2	7	--	10.3	9.2	0
3	8	15	9.9	8.9	0
4	7	19	9.5	8.2	0
5	10	27	8.0	4.0	19

* SWL and apparent SWL (see Section 1) referenced against a 10% SWL solids solution.

Concentrations of SWL in the river vary, depending on the tide stage. At low tide stages, average SWL concentrations range from a near-background 4 ppm at Station 1 to 10 ppm at Station 5 near the mouth of the river. These values are associated with strong freshwater outflows and attending salinities of less than $5^{o}/oo$. Hence, the increase in SWL concentrations between Stations 1 and 5 is attributed to inflows of apparent SWL between these two stations; _i_._e_., inflows of land-drainage and waste discharges from the Simpson Lee kraft mill, the Everett stabilization pond, the Weyerhaeuser lumber mills, and the Weyerhaeuser kraft mill sweet sewer (see Figure 22-1 and Table 23-6). Note that wastes from the Simpson Lee mill, discharged between Stations 1 and 2, make a small contribution (3 ppm discounting any land-drainage contributions) to river SWL concentrations. This is true, also, for the other three waste sources.

At higher tide stages, average SWL concentrations range between 15 ppm at Station 3 to 27 ppm at Station 5. These values are associated with tidal excursions of Port Gardner water into the River and attending salinities of 20°/oo or greater. Since these excursions hold-up river discharges and thereby minimize SWL contributions from upstream sources, these high-water SWL averages derive, principally, from intruding Port Gardner waters; hence, they originate from wastes discharged by the Scott and Weyerhaeuser sulfite mills. At Station 5, high-tide-stage SWL concentrations exceed 25 ppm twenty-five percent of the time and reach maximum values of 50 ppm and greater. These high concentrations occur most frequently from August through mid-October when river discharge is low, thus permitting greater tidal excursion.

Average dissolved oxygen concentrations in the Snohomish River range from 10.5 ppm at Station 1 to 8.0 ppm at Station 5 (Table 24-2). Only at Station 5 do concentrations fall below 5 ppm; 19% of the samples taken had DO concentrations ranging between 4 and 5 ppm and these occurred during low river discharges in September.

Bottom samples collected at 17 points between Stations 1 and 3 (Figure 24-12) defined bottom sediments composed of fine to coarse sand. There is no evidence of sludge or wood fiber accumulations in the river sediments.

DISCUSSION

The Everett area, unlike the Bellingham area, encompasses relatively deep waters. And, although strong water circulation, such as occurs in the Anacortes area, is not available for the rapid transport and dispersion of wastes within and out of the area, water currents and circulation in the Everett area are sufficient to utilize the high volume of dilution water contained therein. The Scott and Weyerhaeuser mills have taken advantage of these geomorphological and hydraulic features by disposing their strong pulping wastes at depth through a deep-water diffuser, and this means of disposal has proved quite effective. Except in and near Everett Harbor, waste concentrations greater than 25 ppm SWL are confined below the 35-foot depth and maximum waste concentrations are contained below the 150-foot depth. Accordingly, excessive pollution of the surface waters of the study area has been alleviated by the transfer of this pollution to the deep waters.

Pollution of the surface waters of the area (0- to 35-foot depths) is caused, almost entirely, by the weak pulping wastes (pulp washing and screening wastes), bleaching wastes, and paper mill wastes generated by these two mills. They are largely responsible for the surface-water waste concentrations that range from background to 25 ppm SWL (excluding Everett Harbor).

Water quality of Everett Harbor is greatly affected because it receives the discharges of the above mentioned weak pulping, bleaching, and paper mill wastes, and because it is affected by the decomposition products evolved from the substantial sludge deposits that cover the Harbor bottom. Water circulation of the Harbor is weak and does not provide sufficient flushing action for maintenance of acceptable water quality. Even though the recent installation of diffuser facilities by the Scott mill has alleviated much of the foam and turbidity that previously characterized the Harbor, this water body is still afflicted with SWL concentrations ranging up to 200 ppm, DO concentrations ranging down to 0 mg/l, low pH levels, and biologically injurious concentrations of sulfides and other toxicants.

Water quality of the Snohomish River is only slightly affected by waste discharges from the Simpson Lee mill, the Everett stabilization pond, and the Weyerhaeuser lumber and kraft mills. A small depression of dissolved oxygen, down to about 8 mg/l average, and a small increase in apparent-SWL concentrations, up to 10 ppm, are the principal influences attributable to these waste sources. Furthermore, although the combined settleable solids discharge from these sources is quite large (see Figure 23-4), current velocities are sufficient to prevent formation of sludge beds within the River. However, eventual sedimentation must occur once these solids are flushed to the River mouth and Port Gardner. Note the large sludge deposit at the mouth of Snohomish River (Figure 24-10). Conversely, pulping wastes from the Scott and Weyerhaeuser mills are carried into the lower reach of the River on flood-tide excursions and these wastes have a detectable influence on water quality--SWL concentrations up to 50 ppm maximum and depressions of dissolved oxygen concentrations down to 4 and 5 mg/l.

In the following sections, attention is given to the adverse effects on marine life caused by the waste concentrations and water quality conditions described above. In preview, the prevailing water quality of Everett Harbor, the lower reach of the Snohomish River, and the surface waters of the broad reaches of the study area has been found to be injurious, or less than satisfactory for many marine forms--juvenile salmon, sensitive early-life stages of shellfishes, and phytoplankton. Details of these damages are fully discussed in the following pages, but of importance here, such damages derive, almost wholly, from the weak pulping, bleaching, and paper mill wastes discharged by the Scott and Weyerhaeuser mills.

25. JUVENILE SALMON

Annually, from April through July, juvenile salmon migrate down the Snohomish River and enter the estuarine waters of the Everett area. Many of these young fish move down the main channel of the River and enter Port Gardner near the entrance to Everett Harbor. Because of their tendency to seek nearshore waters, numbers of these main channel fish enter and move through the Harbor before migrating to schooling areas along the southeastern shore of the Port. However, recorded fish kills and preliminary bioassay studies in 1962 revealed that water quality inimical to juvenile salmon frequently occurs in the Harbor. Recorded observations of fish kills and fish in distress are tabulated in Table 25-1. In all cases, fish were killed rather rapidly, in less than an hour. Fatalities were the result of both toxicity and heavy predation of distressed fish, particularly by sea gulls. In most cases, these kills were associated with detected amounts of the toxic sulfides released from bottom deposits of decomposing sludge. Results obtained in the preliminary *in situ* bioassay studies of 1962 revealed that mortalities always occurred when sulfide concentrations of 0.4 mg/l or greater were detected, and that such mortalities most frequently occurred in those areas of the Harbor surrounding the Scott mill and the Weyerhaeuser mill. On the basis of these findings, further investigation was undertaken (1) to better describe the migratory pathways of Snohomish River juveniles, (2) to verify the occurrence of juvenile salmon in Everett Harbor, and

TABLE 25-1. Observations of fish kills and fish in distress in Everett Harbor, 1962.

Date	Location*	Observation
4/11/62	Between Scott mill & Pier 3	Five chum and one pink salmon fry showed loss of equilibrium and were easily caught in a bucket. Gas bubbles and H_2S odor were noted.
4/24/62	Between Piers 1 & 2	Six pink salmon showed loss of equilibrium and were easily caught in the hand.
5/1/62	Between Piers 1 & 2	Four chum salmon showed distress and were easily caught in a dip net. Their vulnerability to predation was demonstrated in that they were not scared by waving hands over the water--action which would cause the immediate dispersion and escape of healthy fish.
5/14/62	Naval Reserve dock	An estimated 1,500 yellow shiners (pogies) were killed. Before death, these fish showed loss of equilibrium and were observed to be easy prey for sea gulls.
6/16/62	Off northwest corner of Scott dock	An estimated 500 fish, including yellow shiners, starry flounder, and hake, were killed. Before death, fish showed loss of equilibrium and were preyed upon by sea gulls. Floating sludge, gas bubbles, and H_2S odor were noted at the kill site. Water samples collected during the kill had H_2S concentrations as high as 11.0 mg/1. Duration of the kill was about one hour.
6/2/62	Off northwest corner of Scott dock	Sea gulls were seen picking up distressed yellow shiners. Water samples collected during this occurrence had H_2S concentrations greater than 4.0 mg/1.

* See Figure 27-2B for location features.

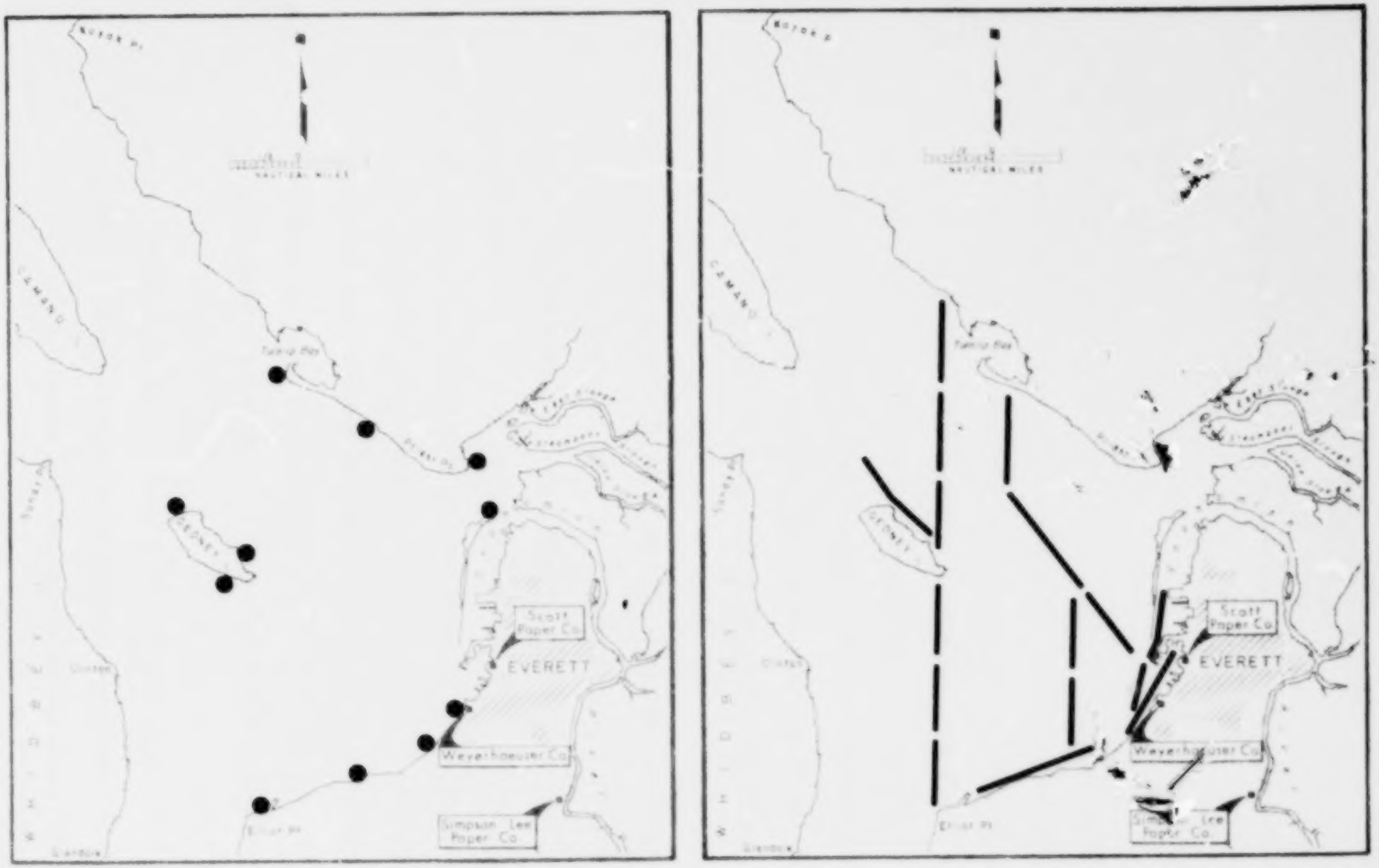
(3) to better define the areas and causes of fish mortality in the Harbor.

STUDIES

Migration Studies. The Fisheries Research Institute (FRI) of the University of Washington conducted studies in the Everett area in 1962, 1963, and 1964 to determine migration routes and schooling areas of juvenile salmon from the Snohomish River. The 1962 study was a preliminary investigation which included both shoreline and offshore sampling of juvenile populations (Tyler, 1963). Shoreline sampling involved a total of 58 beach-seine hauls at various locations along the Gedney Island shoreline, the shoreline between Priest Point and Tulalip Bay, the Tulalip Bay shoreline, and the southern shoreline between Elliot Point and Everett Harbor (refer to Figure 25-1A). Offshore populations were sampled in 51 townet hauls at various locations in Port Gardner and adjacent parts of Port Susan.

In the 1963 FRI study, reported by Tyler (1965), shoreline and offshore salmon populations again were sampled by beach-seine and townet techniques. A total of 131 beach-seine hauls were made at 11 locations (Figure 25-1A) over 22 sampling dates between March 26 and June 28, 1963. A total of 75 townet trawls in 16 offshore sampling areas (Figure 25-1B) were made over 9 sampling dates between April 24 and May 24, 1963.

The 1964 FRI study (Tyler, 1965) was directed principally toward determining the distribution of pink salmon fry in offshore waters. A total of 232 townet trawls in the sampling areas shown in


NAUTICAL MILES
CAMANO
GEDNEY
WHIDBEY
Tulalip Bay
Priest Pt
Clinton
Elliot Pt
Scott Paper Co.
EVERETT
Weyerhaeuser Co.
Simpson Lee Paper Co.

(A)

(B)

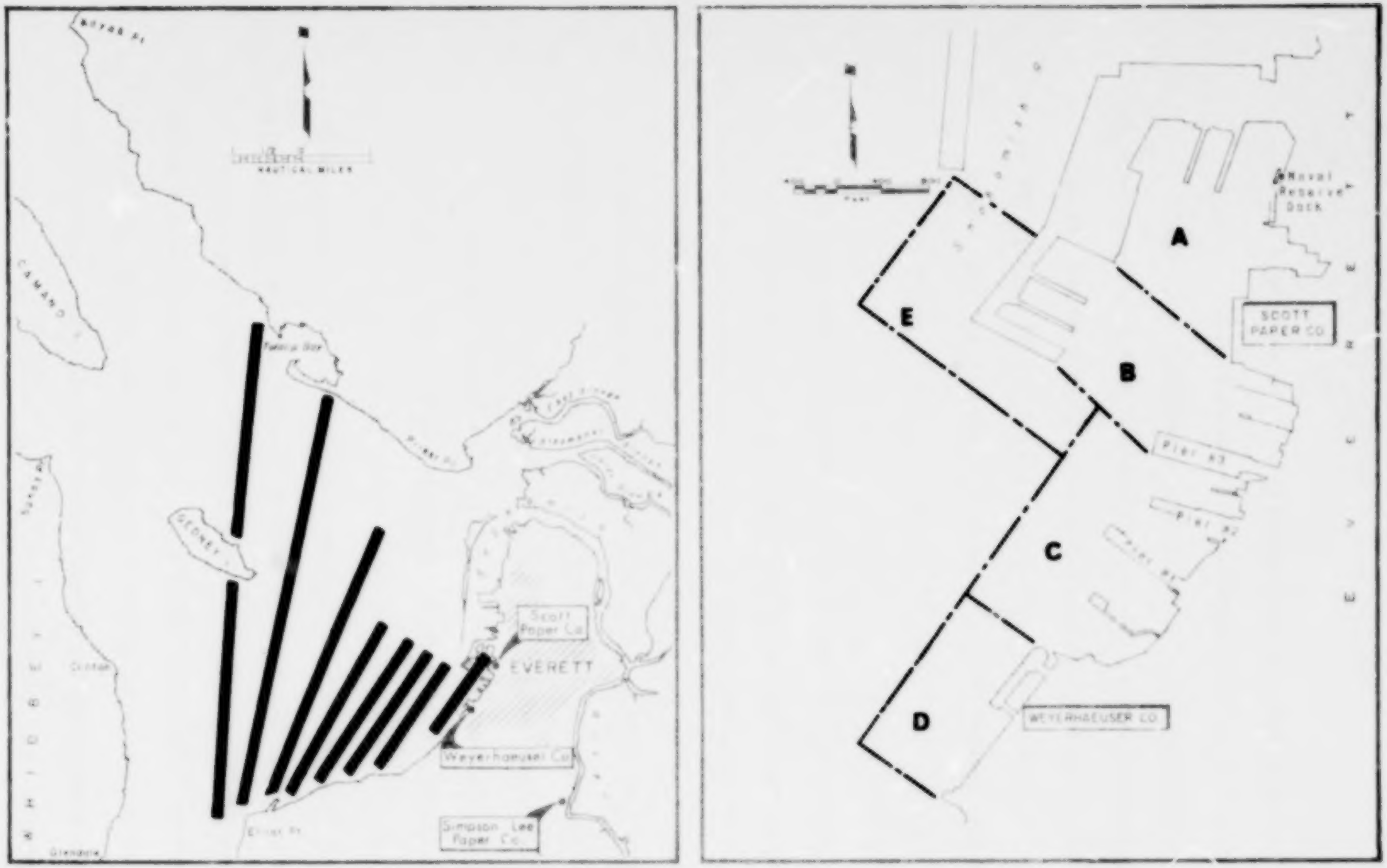
FIGURE 25-1. Area of Port Gardner and Port Susan sampled for juvenile salmon: (A) FRI beach-seining sites in 1963, and (B) FRI townet sampling areas in 1963.

Figure 25-2A were made over 11 sampling dates between April 9 and May 14, 1964. No beach seining was done in this study.

Occurrence Studies. To verify the occurrence of juvenile salmon in Everett Harbor, the Project sampled Harbor fish populations with a mobile fishtrap on five dates in May-June 1962 and two dates in May 1963. The Harbor was divided into five zones (Figure 25-2B) and each zone was sampled on two or more of these dates. Also, when juvenile salmon were sighted in the Harbor, their numbers were estimated and recorded.

Bioassay Studies. The Project and the Washington Pollution Control Commission (WPCC) conducted *in situ* bioassays in Everett Harbor in April and May 1963. The Project study was directed toward delineating areas of the Harbor where test kills, hence lethal conditions, most frequently occur. The WPCC study was designed to determine the cause of test kills by closely monitoring water quality and test fish behavior and mortality during bioassay.

The Project conducted 45 live-box tests at the stations and on the dates listed in Table 25-3. Station locations are shown in Figure 25-8. In each test, ten fish were placed in a live box on station and were exposed in the near-surface water for a period of 2 to 8 hours, unless 100% kill terminated the test in less than 2 hours. Chum salmon fry were used in all tests except those on May 23 when chinook salmon fingerlings were used. During the tests, each live box was visited periodically (every 20 minutes in most tests) to observe test fish mortality and to collect water samples. Wind, weather, and tide stage also were noted.


NAUTICAL MILES
CAMANO
GEDNEY
WHIDBEY
Scott Paper Co.
EVERETT
Weyerhaeuser Co.
Simpson Lee Paper Co.
A
B
C
D
E
FEET
Naval Reserve Dock
SCOTT PAPER CO.
WEYERHAEUSER CO.
EVERETT

(A)

(B)

FIGURE 25-2. Areas in Port Gardner, Port Susan, and Everett Harbor samples for juvenile salmon: (A) FRI townet sampling areas in 1964, and (B) Project fishtrap sampling zones in 1962 and 1963.

The WPCC conducted 14 floating lab tests at the stations and on the dates listed in Table 25-4. Station locations are shown in Figure 25-9. In each test, ten chum salmon fry were placed in the live tank of the lab (Figure 25-3) and were exposed in the near-surface waters for periods of 2 to 6-2/3 hours, unless 100% kill terminated the test in less than 2 hours. The floating lab was designed to accommodate three operators plus equipment, so that during a test, fish behavior and mortality could be continuously observed and water samples (pumped from inside the live tank) collected at intervals of 20 minutes or less.

METHODS

Migration Study Methods. FRI used a 256x12-foot beach seine in their 1962 and 1963 studies. For each sample, this net was laid out from a skiff and hauled into shore. Fish captured were identified and counted.

In most FRI townet sampling, the net used measured 10x20 feet at the entrance, and tapered back 46 feet to a zippered cod end. Mesh sizes decreased from 3-1/2 inches (stretch mesh) at the entrance to 1.2 inches, 0.8 inch, and to 0.2 inch (bobbinet) at the cod end. In some of the early tows of the 1963 study, a net with a 9-foot square entrance was used. For each sample, the net was towed behind two boats for a fixed period of time and was then hauled in for identification and counting of fish captured. In 1963, tows were normally for 15 minutes, but occasionally, for 30 minutes. Tow periods in the 1964 study were 5 minutes.

Occurrence Study Methods. The mobile fishtrap used for sampling salmon populations in Everett Harbor is described in Section 8 and illustrated in Figure 8-3. To obtain a sample, this trap was run within a zone (see Figure 25-2B) for a period ranging from 20 to 84 minutes. After each run, captured fish were identified and counted.

Bioassay Methods. Fish used in both the live-box and floating-lab bioassays were chum fry or chinook fingerlings captured by beach seining in the Snohomish River main channel or delta. These fish were kept in a holding box in the main channel (see Figure 25-7A) for not less than 24 hours prior to use. Only those fish in good condition were used in the tests, and none was used more than once. Handling techniques were the same as those described in Section 8.

The live boxes used in the Project studies were the same as those described in Section 8 and illustrated in Figure 8-4.

The floating lab used by WPCC is pictured in Figure 25-3. It was a floating platform with a center opening through which was suspended a live tank (24 inches x 48 inches x 36 inches deep) covered with 16-mesh screen. The top of the tank was opened to facilitate observation of test fish. Water samples from inside the tank were pumped with either a hand-operated bilge pump or a 12-volt centrifugal pump and were analyzed, except for salinity, on board the float.

Water sample analyses by WPCC and the Project were as follows:

Temperature:	with a mercury thermometer.
DO:	by the Alsterberg modification of the Winkler method (A.P.H.A., 1962).

pH: with a Beckman, Model N, meter.

Total Sulfides: by the methylene blue colorimetric method (A.P.H.A., 1962).

Salinity: with a Hytech, Model RS-7A, inductive salinometer.

Residual Chlorine: by the orthotolidine method (A.P.H.A. 1962).

RESULTS

Migration. Beach-seining results from FRI's 1962 study show major schooling areas of chum, pink, and silver salmon near Elliot Point and around Gedney Island (Figure 25-4). Minor schooling areas were found along the southern shore of Port Gardner (northeast of Elliot Point), and in and outside of Tulalip Bay. Offshore townet catches of juveniles were obtained in Tulalip Bay and contiguous outside waters; in the delta area off of Steamboat Slough; and in Port Gardner near Everett Harbor and southwest thereof. Altogether, 1962 results indicate that Snohomish River outmigrants move in all directions (Figure 25-4) and are distributed throughout Port Gardner and contiguous waters.

Beach-seining results from FRI's 1963 study are summarized in Figure 25-5. Values shown are the average catches of chum, silver, and chinook juveniles (no pinks in 1963) per beach-seine haul at each of the seining sites depicted in Figure 25-1A. Note that young salmon school along all shorelines accessible from the Snohomish River. Also note that juveniles school on the southern shoreline near the entrance of Everett Harbor.

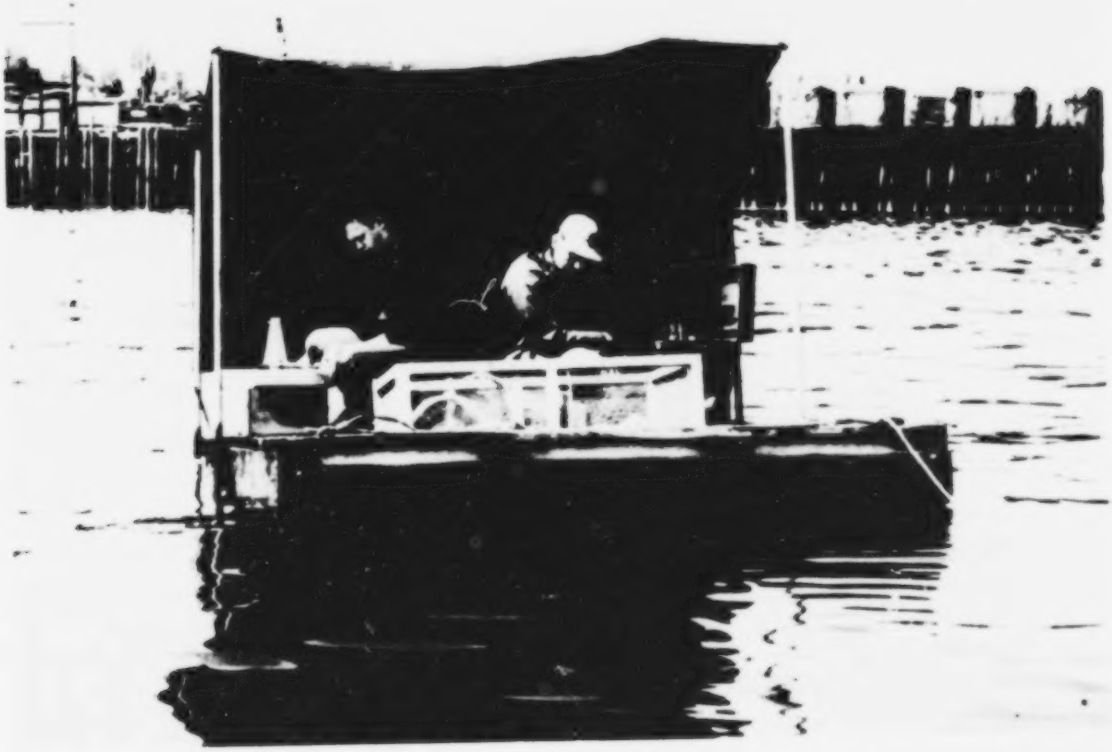


FIGURE 25-3. Floating lab used for in situ bioassay studies by the Washington State Pollution Control Commission.

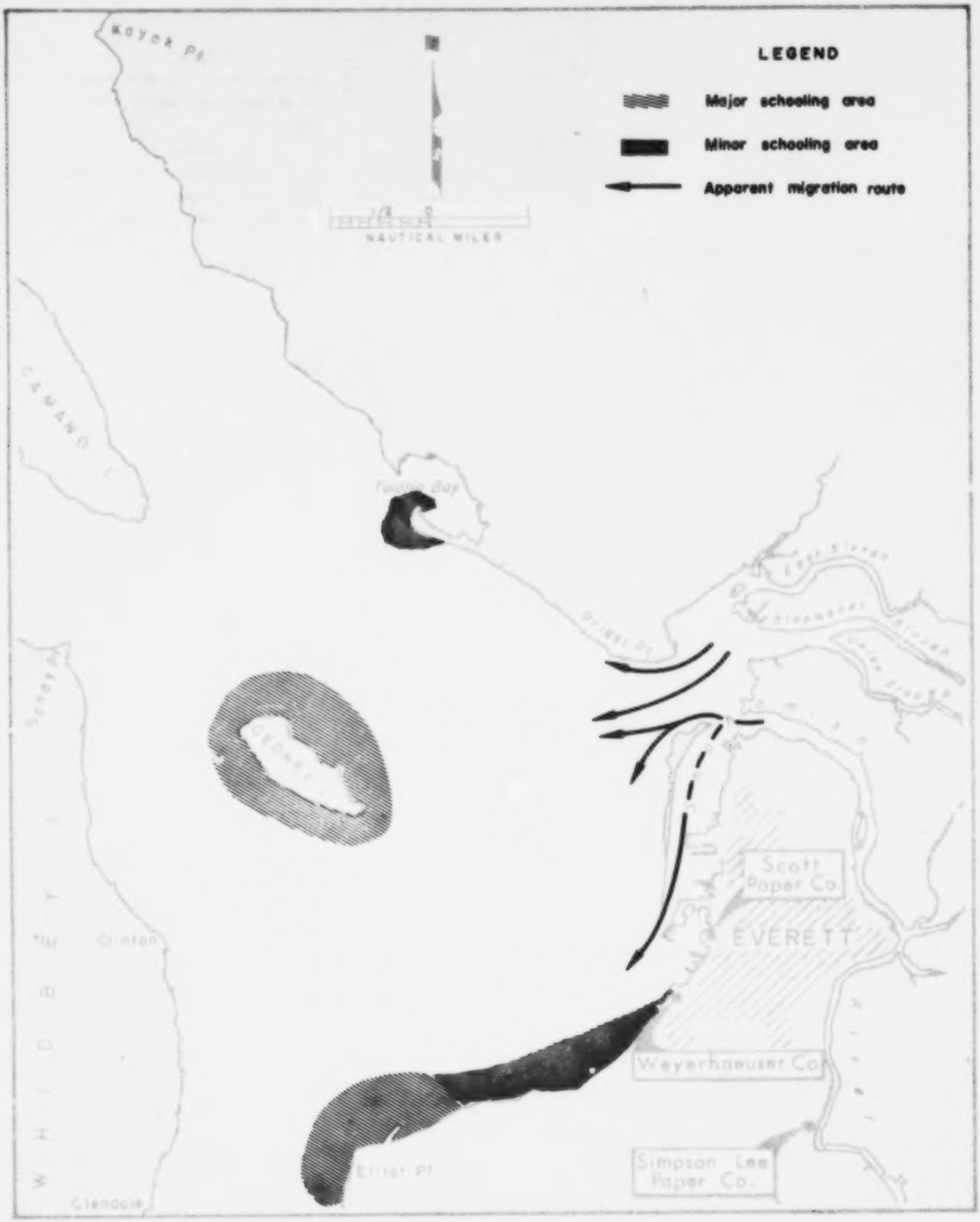

LEGEND
Major schooling area
Minor schooling area
Apparent migration route
1/2 0
NAUTICAL MILES
Kayak Pt
Tulalip Bay
Priest Pt
East Slough
Steamboat Slough
Union Slough
CAMANO I
GEDNEY
Sandy Pt
Clinton
WHIDBEY
Glendale
Elliot Pt
Scott Paper Co.
EVERETT
Weyerhaeuser Co.
Simpson Lee Paper Co.

FIGURE 25-4. Major and minor schooling areas and apparent migration routes of chum, pink, and silver juveniles out of the Snohomish River; FRI 1962 study.

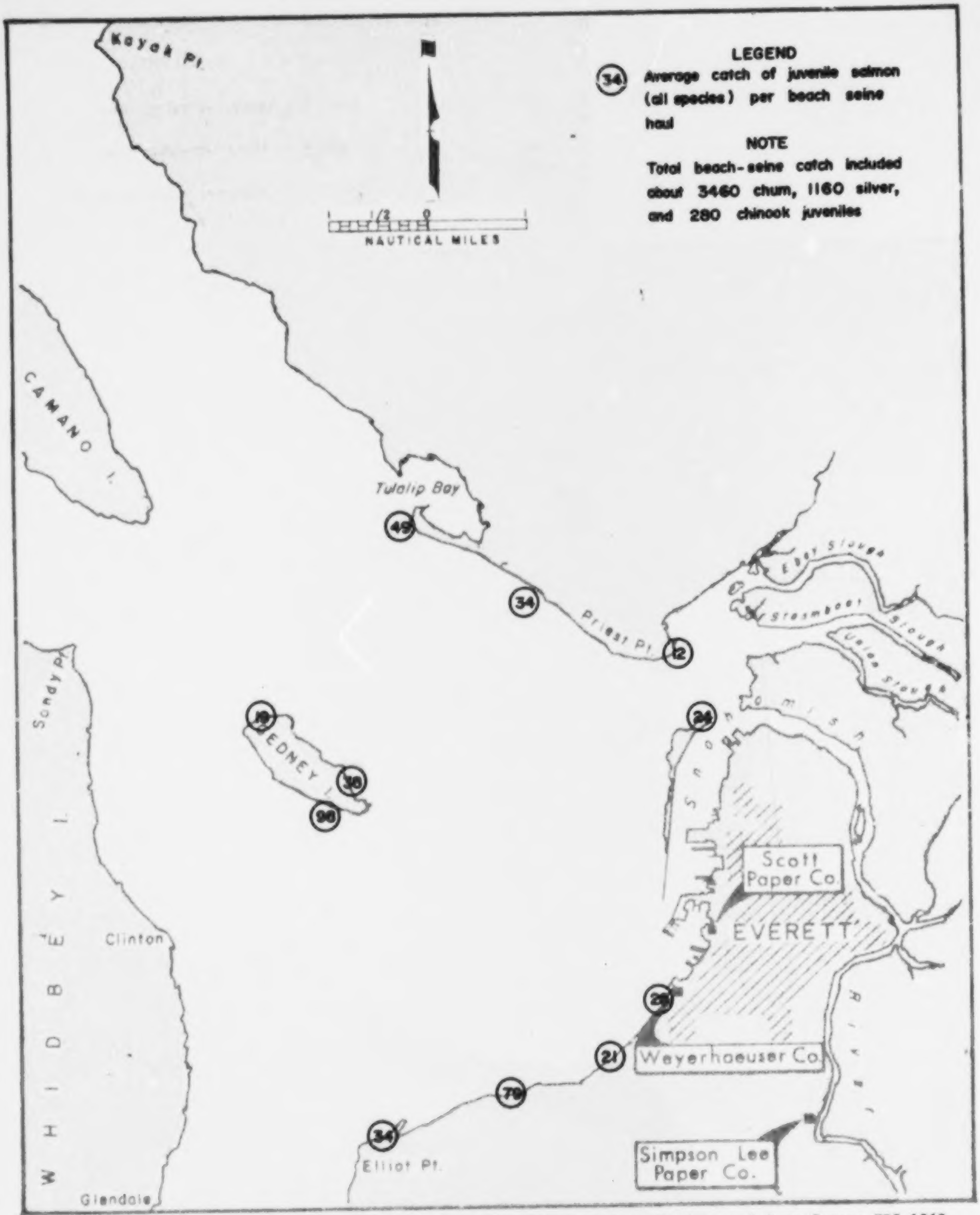

LEGEND
34 Average catch of juvenile salmon (all species) per beach seine haul
NOTE
Total beach-seine catch included about 3460 chum, 1160 silver, and 280 chinook juveniles
1/2
0
1
NAUTICAL MILES
Kayak Pt.
CAMANO I.
Tulalip Bay
49
34
Priest Pt.
12
Ebey Slough
Steamboat Slough
Union Slough
Snohomish
24
19
EDNEY I.
36
96
Sandy Pt.
WHIDBEY I.
Clinton
Scott Paper Co.
EVERETT
28
21
Weyerhaeuser Co.
River
79
34
Elliot Pt.
Simpson Lee Paper Co.
Glendale

FIGURE 25-5. Average shoreline catches of juvenile salmon in Port Gardner and Port Susan; FRI 1963 study.

Townet results from FRI's 1963 study are summarized in Figure 25-6. Values shown are average area catches of juvenile salmon (all species) per 10 minutes of tow for all tows made in the areas delineated in Figure 25-1B. Note the relatively even distribution of juveniles (mostly chum and silver fry) in the offshore waters. Note, also, that (1) sizable catches of young salmon were obtained in the main channel of the Snohomish River a short distance above its discharge into Port Gardner, and (2) juveniles were caught near and inside Everett Harbor.

In FRI's study of 1964, pink salmon fry dominated offshore townet catches during the two sampling periods: April 9-14 (1,901 pinks out of 1,970 total juveniles) and April 24-29 (397 pinks out of 458 total juveniles). These pink fry were concentrated in the deeper waters of Port Gardner and Port Susan (Figure 25-7A) and few were captured in the Inner Harbor and contiguous waters. Whether or not pinks also were schooling in shoreline waters was not determined, because no beach seining was done. If, in fact, pinks were concentrated only in offshore waters in April 1964, this distribution differed from that observed in April 1962 when FRI beach-seine sampling found dominant populations of pink fry in all of the schooling areas depicted in Figure 25-4, but townet sampling captured few fish in offshore waters.

FRI townet results obtained during May 11-14, 1964--after the peak of the pink migration--reveal a relatively even distribution of juveniles of all species throughout Port Gardner and adjacent

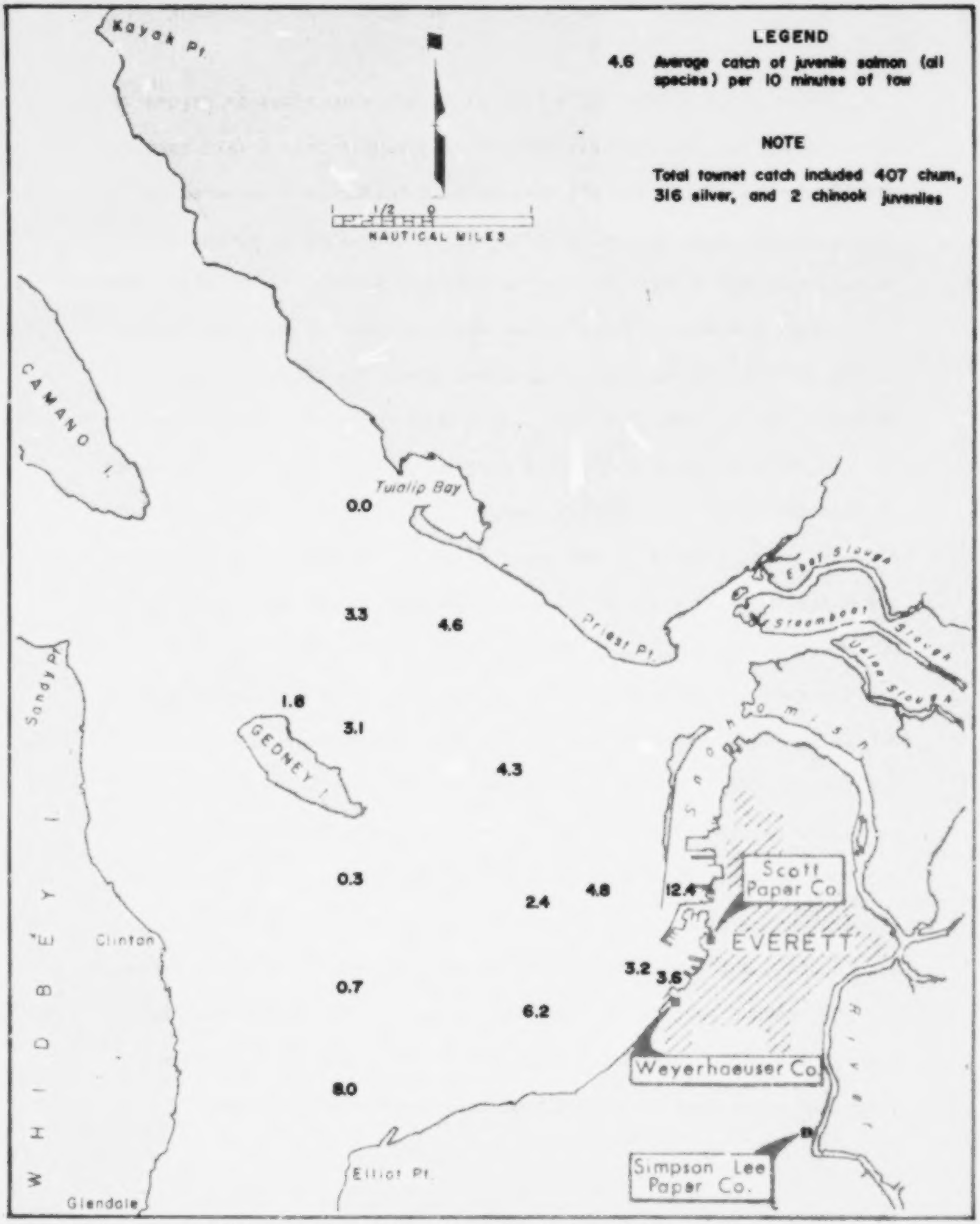

LEGEND
4.6 Average catch of juvenile salmon (all species) per 10 minutes of tow
NOTE
Total townet catch included 407 chum, 316 silver, and 2 chinook juveniles
1/2
0
1
NAUTICAL MILES
Kayak Pt.
CAMANO I.
Tulalip Bay
Priest Pt.
Ebey Slough
Steamboat Slough
Union Slough
Snohomish
Sandy Pt.
GEDNEY I.
WHIDBEY I.
Clinton
Glendale
Elliot Pt.
EVERETT
Scott Paper Co.
Weyerhaeuser Co.
Simpson Lee Paper Co.
River
0.0
3.3
4.6
1.6
3.1
4.3
0.3
2.4
4.8
12.4
3.2
3.6
0.7
6.2
8.0

FIGURE 25-6. Average offshore catches of juvenile salmon in Port Gardner and Port Susan; FRI 1963 study.

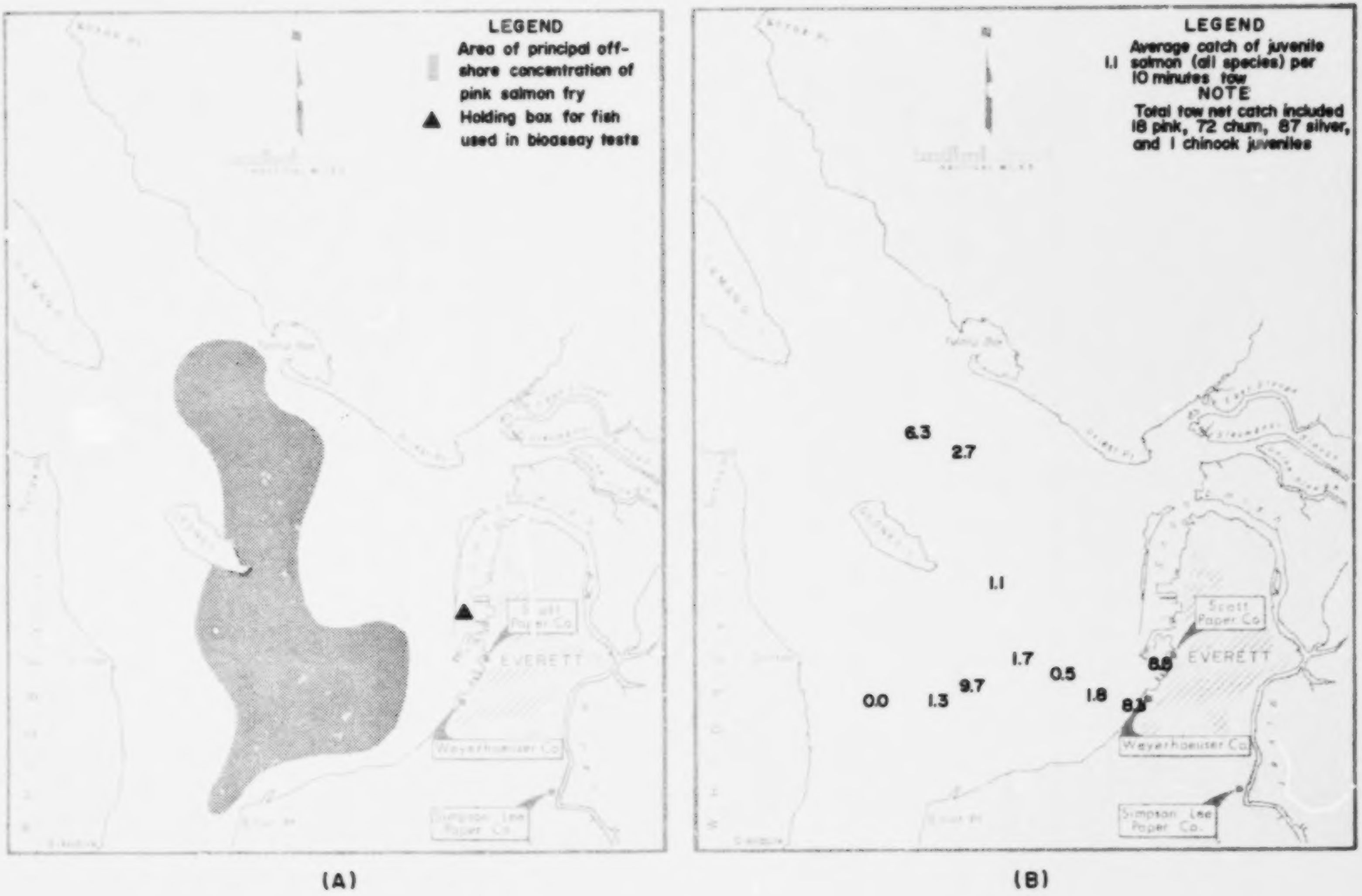

LEGEND
Area of principal offshore concentration of pink salmon fry
▲ Holding box for fish used in bioassay tests
Scott Paper Co.
EVERETT
Weyerhaeuser Co.
Simpson Lee Paper Co.
(A)
LEGEND
1.1 Average catch of juvenile salmon (all species) per 10 minutes tow
NOTE
Total tow net catch included 18 pink, 72 chum, 87 silver, and 1 chinook juveniles
6.3
2.7
1.1
1.7
0.5
1.8
8.8
8.1
9.7
1.3
0.0
Scott Paper Co.
EVERETT
Weyerhaeuser Co.
Simpson Lee Paper Co.
(B)

FIGURE 25-7. Offshore distribution of juvenile salmon in Port Gardner and Port Susan in 1964: (A) offshore concentration of pink salmon fry during April; and (B) offshore catches of all species of juvenile salmon during May. FRI 1964 study.

Port Susan waters (Figure 25-7B). Note that during this period, juveniles were caught in and near Everett Harbor.

Occurrence of Juveniles in Everett Harbor. Fishtrap catches of juvenile salmon in Everett Harbor in 1962-63 are given in Table 25-2. Note that young salmon were caught in all five zones of the Harbor (see Figure 25-2B), and that all four species were represented in the total catch. Also, schools of chum and pink juveniles (from several fish to an estimated 1,800 fish per school) were sighted in Zones B and C on eight different occasions in 1962-63. These data, therefore, evidence the utilization of the Inner Harbor by migrating Snohomish River juveniles.

TABLE 25-2. Numbers of juvenile salmon caught in Everett Harbor, 1962-63

	Zone					Total Inner Harbor
	A	B	C	D	E	
Chum	5	3	139	0	0	147
Silver	6	3	20	10	0	39
Pink	16	15	124	27	18	200
Chinook	9	12	35	14	3	73
Total minutes of sampling	148	146	280	140	50	

Occurrence of Mortality. Percent mortalities observed at termination of live-box bioassays in which exposure periods were less than 8 hours are given in Table 25-3. Stations and data are arranged by area (see Figure 25-8) in accordance with the frequency and intensity of mortalities observed. The following facts are evident:

1. In Area A, kills occurred in seven of eight tests, and three of these were 100% kills.
2. In Area B, kills occurred in six of twelve tests, and two of these were 100% kills.
3. Throughout the remainder of Everett Harbor, complete survival was noted in all but four tests wherein only 10% mortality was recorded.
4. Zero mortality was observed in all but one (20% kill) of the control tests outside the Harbor.

These results clearly show that Areas A and B are zones where conditions inimical to juvenile salmon survival frequently occur.

Water Quality Associated with Mortalities. In four of the five live-box tests in which 100% kill occurred, distress and subsequent mortality were associated with the release of sulfides (probably H_2S) from decomposing sludge on the bottom of the Harbor; viz.,

Station 2 on May 9 - 100% mortality occurred within ten minutes after floating sludge, gas bubbles, and H_2S odor suddenly appeared around the live box. Immediately prior to this release of bottom material, a log raft

TABLE 25-3. Percent mortalities at termination of live-box tests in which exposure periods were 8 hours or less; Everett area, May 1963.

Area	Station	Date 5/7/63	 5/9/63	 5/21/63	 5/22/63	 5/23/63
A	1	70	100			0*
	2		100			
	3	30				100*
	4	30	70			
B	19			0	100	
	20				0	
	21			30	10	
	22			10	100	
	23	0		0	0	
	24			20	0	
Remainder of Everett Harbor	5		0			10*
	6					0
	7	0				
	8		0			
	9	0				
	10					10*
	11					10*
	12	0				0*
	13					0*
	14					0*
	15	0				
	16					0*
	17			0	10	
	18	0		0	0	
Control Area	25	0		0	20	
	26	0		0		0*

*Chinook fingerling used in these tests. Otherwise chum fry were used.

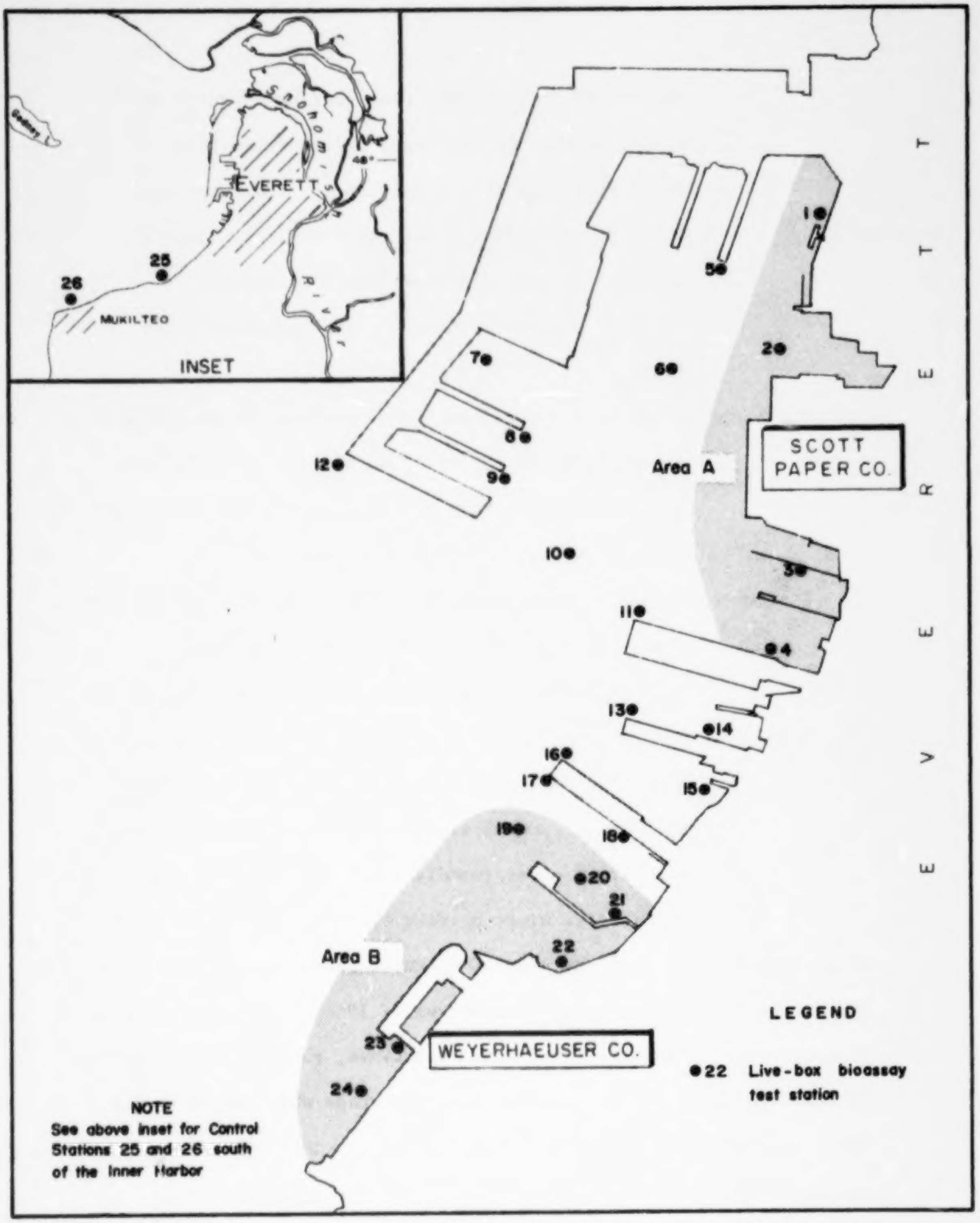

Gedney
SNOHOMISH RIVER
EVERETT
48°
25
26
MUKILTEO
INSET
1
5
2
6
7
8
9
12
Area A
SCOTT PAPER CO.
10
3
11
4
13
14
16
17
15
19
18
20
21
22
Area B
23
WEYERHAEUSER CO.
24
EVERETT
LEGEND
● 22 Live-box bioassay test station
NOTE
See above inset for Control Stations 25 and 26 south of the Inner Harbor

FIGURE 25-8. Live-box bioassay test stations and Areas A and B in the Everett Harbor.

was pulled through this area causing substantial mixing of the shallow water column (then about 10-15 feet deep at a minus tide). Subsequently, while floating sludge was still present, immediate distress of test fish and 100% kill within 10 to 30 minutes resulted in each of three repeat tests.

Station 4 on May 23 - a total-sulfide concentration of 2.0 mg/l was measured at the live box at the time that 100% kill was noted. This kill occurred at low tide and after an exposure period of 55 minutes.

Station 19 on May 22 - a 100% kill of test fish occurred one hour after low tide and 20 minutes after sulfides (0.1 to 0.2 mg/l) were first detected at the station.

Station 22 on May 22 - 100% kill of test fish occurred 70 minutes after low tide and 25 minutes after total sulfides (0.3 mg/l) were first detected at the station. Also, test fish showed immediate distress and 60% died within five minutes after sulfides were first noted.

These observations are very similar to those noted in the fish kills and in the preliminary _in situ_ bioassays of 1962; _i.e._, mortalities, in most cases, were associated with detectable, but low, concentrations of sulfides occurring at or about low tide stage when reduced water depth allowed surface waters to be affected by toxic H_2S released from bottom sludge.

Results from the floating-lab bioassays are summarized in Table 25-4. Data are arranged by area (see Figure 25-9) and, within each area-grouping, are arranged into two mortality-groupings: (1) data from tests in which mortality occurred and (2) data from tests in which no mortality occurred. The following features are evident:

1. With but two exceptions, all kills observed at the floating lab were associated with detected concentrations of total sulfides, whereas observations of no-kill were associated with the absence of detectable sulfides. At Station 1 on May 21, a 90% kill occurred with zero sulfides but with DO concentrations of 0.0 mg/1 minimum and 1.7 mg/1 median; hence hypoxia was probably responsible. At Station D on April 27, there occurred the only instance of complete survival when total sulfides were detected.
2. Dissolved oxygen concentrations were generally somewhat lower in tests in which mortalities occurred than in tests wherein complete survival obtained. However, except for the hypoxia situation noted above, it appears that DO deficiency was not a primary cause of mortality, although it may have intensified sulfide-caused kills.
3. Test fish reactions to total sulfides were immediate distress and abnormal behavior, followed by mortality within 20 to 45 minutes (refer to 100% kills at Stations B, E, K, and I).

The above facts implicate sulfides as being the toxicant causing most test fish kills in Everett Harbor. However, three situations

TABLE 25.4. Percent terminal mortalities and summary of water quality data from the floating-lab bioassay tests in the Inner Harbor.

Area	Station	Date	Mort. (%)	Exposure Time		Total Sulfides (mg/1)		DO (mg/1)		pH		Salinity (°/oo)	Temp. (°C)
				(hrs)	(mins)	max.	med.	min.	med.	min.	med.	med.	med.
A	B	5/14/63	100	0	40*	1.7	0.2	5.2	5.8	6.4	6.5	20.7	13.3
	E	4/19/63	100	0	45*	1.0	0.3	3.0	3.6	5.9	6.1	-	10.7
	A	4/26/63	0	4	20	0	0	3.9	4.6	6.3	6.7	17.7	11.4
	C	5/9/63	0	3	40	0	0	6.6	7.1	6.1	6.3	15.4	12.9
	D	4/27/63	0	4	40	0.5**	0	5.5	7.7	6.5	6.8	20.2	10.3
	E	5/7/63	0	3	0	0	0	6.6	7.2	6.6	6.6	21.1	11.3
	E	5/23/63	0	6	40	0	0	6.4	7.6	4.7	5.5	16.0	16.0
	F	5/27/63	0	5	0	0	0	6.6	7.6	6.3	6.4	20.2	15.4
B	K	5/24/63	100	0	20*	0.2	0	3.0	4.5	-	-	12.3	13.2
	I	5/22/63	100	0	40*	0.2	0.1	6.0	6.6	3.0	5.9	18.9	14.6
	I	5/21/63	90	2	0	0	0	0	1.7	5.7	6.2	19.4	17.1
	J	5/25/63	0	5	50	0	0	8.2	9.1	7.2	7.5	18.7	14.0
Remainder of Inner Harbor	H	4/25/63	10	2	0	0.2	0.1	5.5	6.1	6.0	6.8	-	10.0
	G	5/8/63	0	3	20	0	0	4.8	4.9	6.5	6.7	21.9	12.4

* Lapse time between first observation of distress and 100% mortality.

** This maximum (0.5 mg/1) was collected at the surface. At the normal sampling depth of 6 inches, maximum total sulfides concentration was 0.1 mg/1.

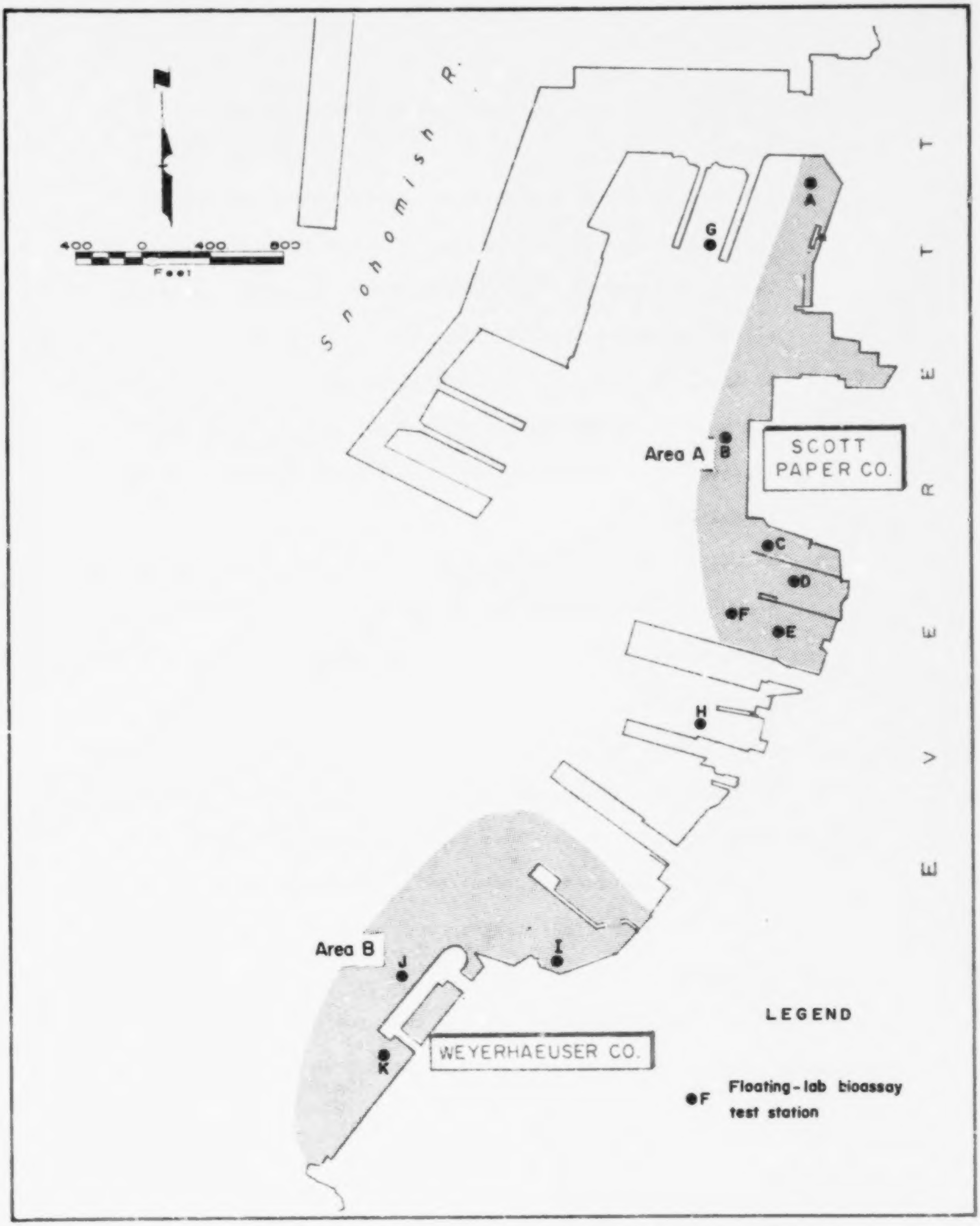

Snohomish R.
400
0
400
800
Feet
G
A
Area A
B
SCOTT PAPER CO.
C
D
F
E
H
EVERETT
Area B
J
I
K
WEYERHAEUSER CO.
LEGEND
●F Floating-lab bioassay test station

FIGURE 25-9. Floating-lab bioassay test stations in the Everett Harbor.

evidence the occasional occurrence of other toxicants fatal to juvenile salmon:

1. On April 11, 1963, 0.4 mg/l of residual chlorine was detected in the water in front of the Scott mill. Test fish were bioassayed in this water with 80% mortality resulting within 10 minutes and 100% mortality within 19 minutes.
2. On April 12, 1963, residual-chlorine concentrations exceeding 1.0 mg/l again were detected in front of the Scott mill. A bioassay with chum salmon fry resulted in mortalities within 3 minutes.
3. On May 9, 1963, blue-green wastewater, presumably discharged from the Scott mill whitewater sewer (see Figure 23-1), appeared at the surface and drifted into the area of Station 2 (Figure 25-8). A routine live-box bioassay was being conducted at this station at the time, and immediate distress of test fish followed by 100% mortality within 13 minutes was observed. While these blue-green wastes surrounded the station, a second test resulted in 100% mortality within 10 minutes after test fish showed immediate distress upon being placed in the live box.

These results evidence the discharge of chlorine and other wastes that are acutely toxic and capable of killing wild fish occurring in the Harbor.

DISCUSSION

Migration and occurrence study results (Figures 25-4, 25-5, 25-6, and 25-7B, and Table 25-2) clearly show that juvenile salmon occur in and immediately outside of Everett Harbor. Bioassay results (Tables 25-3 and 25-4) show that water quality in the larger part of the Harbor--excluding Areas A and B--is usually acceptable for juvenile salmon survival. Consequently, it is concluded that, of the many juvenile salmon that migrate down the Snohomish River main channel and enter Port Gardner near the Harbor entrance, substantial numbers move, without inhibition, into and through the Harbor.

Observed fish kills (Table 25-1) and bioassay results (Table 25-4 and test) show, however, that fish utilizing the Harbor can occasionally encounter toxic concentrations of sulfides, chlorine, or other toxicants. Toxic conditions develop so rapidly that they entrap fish by causing immediate disorientation so that their ability to escape to waters of favorable quality is severely inhibited. While thus distressed, fish suffer either abnormally high predation or fatalities due to continued exposure to the ambient toxicity. Therefore, it is concluded that juvenile salmon (and other fish) that utilize the Harbor have been killed by toxic conditions that intermittently occur therein.

Results presented in Tables 25-1 and 25-4, and in the accompanying text, show that juvenile salmon suffer morbidity and, usually, mortality whenever detectable amounts of sulfides, hydrogen sulfide, or residual chlorine are measured or observed. Also, morbidity and mortality have been observed in association with blue-green wastes (which presumably contained some unknown toxicant) discharged by the Scott mill and with waters low in dissolved oxygen. On the basis of these and the above findings, therefore, it is recommended that the following water quality criteria be met at all times and at all points in Everett Harbor to assure protection of young salmon and other fishes:

Total sulfides	no detectable amount
Residual chlorine	no detectable amount
DO	greater than 5 mg/l

To ensure that these criteria are met, and to prevent damage from other agents or waste components that are toxic to marine fishes, it is further recommended that water quality throughout the Harbor be adequate for the survival and normal behavior of juvenile salmon during 4-hour, in situ bioassays similar to the live-box tests described in Section 8.

Suspended solids contained in the several waste streams discharged into the Inner Harbor by the Scott and Weyerhaeuser mills (see Section 23) and wood chips spilled during unloading of chip barges at both mills are the principal sources of the toxic concentrations of sulfides that have occurred in the Harbor. A substantial portion of these organic solids settle in the Harbor and form the sizable sludge deposits depicted in Figure 24-10. Anaerobic decomposition of this sludge produces H_2S (among other products), and this is released in toxic concentrations to surface waters during low tides or when boat traffic mixes the water column. Both phenomena, however, are the result of weak circulation and flushing of the Harbor; i.e., sufficient detention time in the Harbor permits settling of suspended solids, and inadequate transfer of oxygen to the bottom waters allows the development of anaerobic conditions in the sludge mass.

Summarily, the Harbor does not have the capacity to accept large amounts of organic waste solids without the consequential development of anaerobic sludge deposits. Abatement of H_2S toxicity and compliance with the H_2S criteria previously recommended, therefore, will require a substantial reduction in the discharge of suspended solids by the Scott and Weyerhaeuser mills to alleviate future sludge accumulation and will necessitate the removal of existing sludge deposits.

Discharges of chlorine and other toxicants--possibly slime control agents, cleansing agents, or dyes--have been the detected or apparent causes of the non-H_2S toxicity observed in the Harbor. Because of weak circulation in the Harbor and lack of adequate dispersive facilities at the termini of mill sewers,* these materials, after discharge, persist in toxic concentrations for protracted periods of time before dispersion and dilution to non-damaging levels. Consequently, abatement of these toxic conditions will require, primarily, the prevention of all discharge of such toxic materials into the Harbor and, secondarily, the provision of multiport diffusers on all outfall sewers.

* The Scott mill now discharges all but whitewater wastes through multiport diffusers (see Figure 23-1).

26. BOTTOM ORGANISMS

It is shown in Section 24 that settleable solids in the wastes discharged by the Scott and Weyerhaeuser mills have caused considerable accumulation of sludge in Everett Harbor and adjacent outside waters. Also, the quality of these waters is affected by concentrations of bleaching, weak pulping, and other process wastes, all of which are potentially toxic to marine life. Such conditions can have a deleterious effect on bottom-dwelling organisms and on the fauna of the shoreline intertidal zone, and for this cogent reason, the Project conducted several benthic studies in the Everett area.

STUDIES

Two studies were undertaken to assess the effects of sludge deposits on the benthic community of Everett Harbor. On May 16, 1962, sediment samples, one from each station, were collected at the 20 stations in the Harbor (Figure 26-1). These were analyzed for sediment volatile solids content, and examined for the included benthos. In the second study, during May 22-24, 1962, sediment samples were taken from 16 stations in Port Gardner, outside of the Harbor (Figure 26-2A). The purpose of this investigation was to evaluate the structure of benthic communities in areas not affected or little affected by accumulated sludge. Samples from the studies were analyzed and examined in the same manner as those of the first study.

In addition to the above, a third investigation was undertaken

Preceding page blank

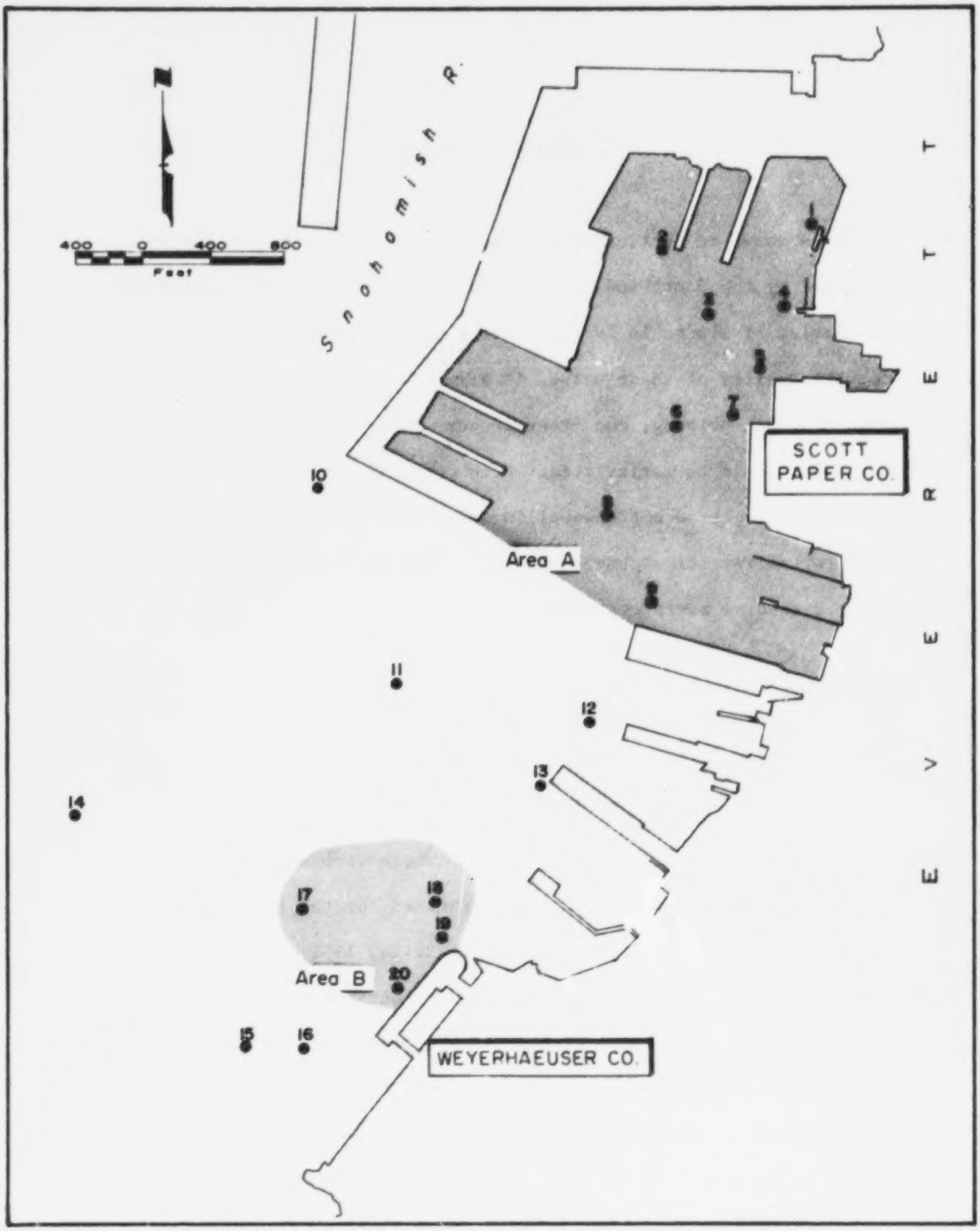

N
400
0
400
800
Feet
Snohomish R.
EVERETT
SCOTT PAPER CO.
WEYERHAEUSER CO.
Area A
Area B
1
4
7
10
11
12
13
14
15
16
17
18
19
20

FIGURE 26-1. Sediment sampling stations in Everett Harbor, May 16, 1962.

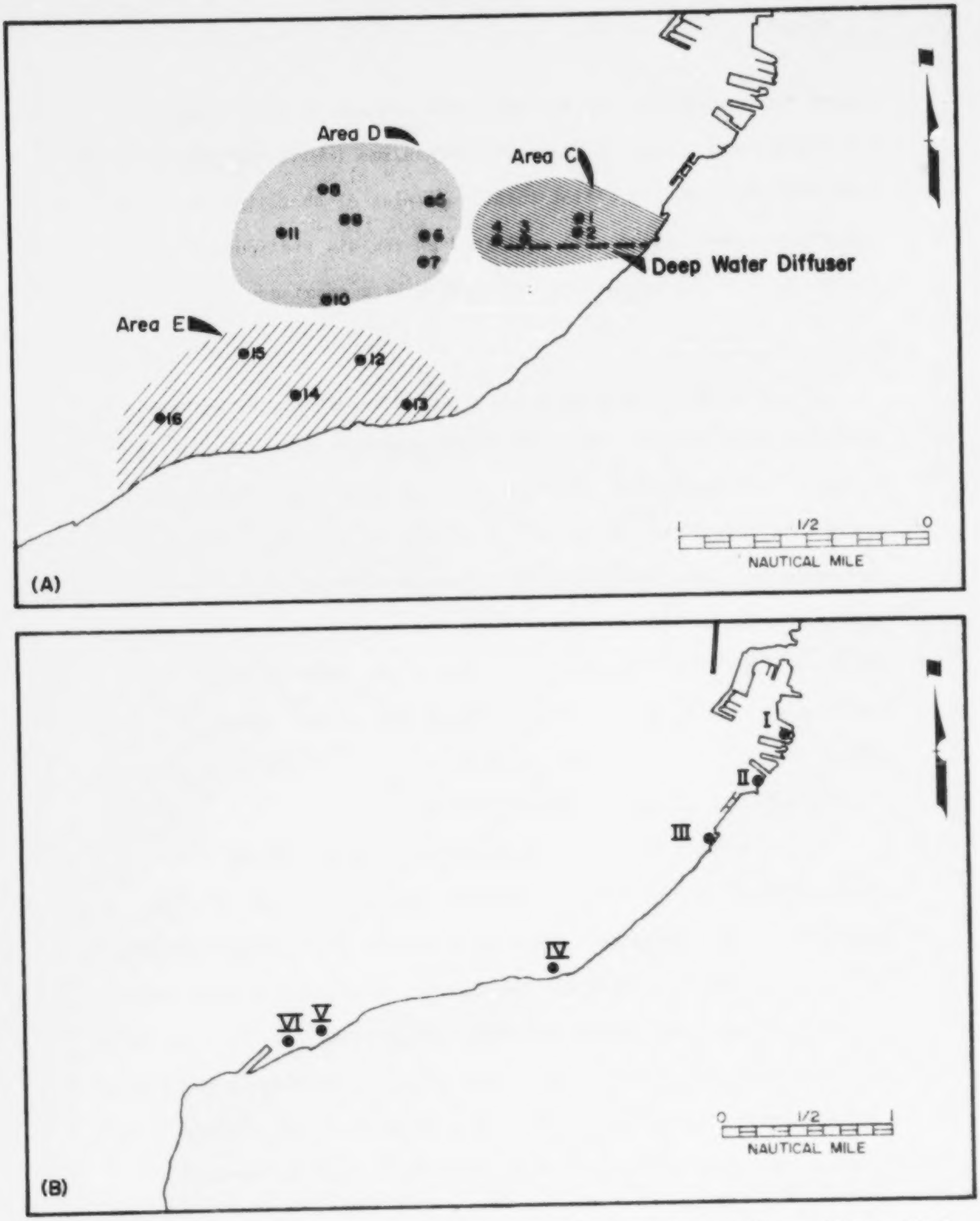

Area D
Area C
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Deep Water Diffuser
Area E
1
1/2
0
NAUTICAL MILE
(A)
I
II
III
IV
V
VI
0
1/2
1
NAUTICAL MILE
(B)

FIGURE 26-2. (A) Sediment sampling stations in Port Gardner, May 22-24, 1962, and (B) Intertidal sampling stations on the Port Gardner shoreline, May 22-24, 1962.

during May 22-24, 1962, to determine the effects of water quality and accumulated sludge on intertidal organisms inhabiting the shoreline from Everett Harbor to Elliot Point. Samples of shoreline substrata and samples from piling were collected at the six stations shown in Figure 26-2B. The benthos of each sample were examined.

METHODS

Bottom samples taken in Everett Harbor on May 16, 1962, were collected with a 0.125-cubic-foot Ekman dredge, modified by having a 40-mesh screen mounted under the top flaps and a two-foot diameter steel shoe encircling the dredge to prevent sinking into soft sludge and sediment. Samples were brought aboard the boat, were sifted with a 40-mesh screen, were preserved, and were transported to the laboratory for identification and enumeration, under microscope, of included benthic life. Sediment volatile solids were analyzed by the method in A.P.H.A. (1962), and results thereof were expressed as percent volatile solids, dry-weight basis.

Bottom samples taken in Port Gardner during May 22-24, 1962, were collected with a clamshell snapper, except at Station 2 where a Peterson dredge was used. These were brought on board and examined for a description of sediment constituents, odors, and visible organisms. A portion of each was placed in a plastic bag, iced, and transported to the laboratory for volatile solids analysis. The remaining portion of each was washed and concentrated with a 40-mesh screen, preserved, and taken to the same laboratory for identification and enumeration of entrained organisms.

At each station in the intertidal study of May 22-24, 1962, square-foot and core samples of the shoreline substrata were collected at sampling points positioned along transects (one at each station) laid out perpendicular to the water's edge and extending from the high-tide mark to the front of the ebbing tide (low tides were -1.3 to -1.9 feet during the study). The locations of sampling points, substratum characteristics, and other information are given in Table 26-1. Also, in this study, samples were taken from piling located at or near each station.

A single square-foot sample was taken at each sampling point except Point A at Station II. A square-foot metal frame was used to delimit a randomly selected area. Substratum within the frame was dug out to a depth of six inches and was sifted through a 40-mesh screen. The screened samples were bottled and preserved, and taken to the laboratory for examination.

Two core samples were collected at each sampling point except Point B at Station III and Point A at Station V. These were collected with a two-inch (I.D.) plastic tube pushed to a depth of two inches. The two samples were composited, preserved with 4% formalin, and taken to the laboratory for subsequent examination.

Piling samples were taken with a square-foot frame to delimit a randomly selected area. A single sample was taken at each of Stations I, II, III; two samples were taken at Station IV; and four samples were collected at Station V-VI. Samples were taken about midway between the high- and low-water marks on the piling. Organisms were scraped from the piling with a wood chisel and were bottled, preserved, and shipped to the laboratory.

TABLE 26-1. Information on sampling points from which square-foot and core samples were collected in the intertidal study.

Station	Sampling Points: linear feet seaward of the high tide mark & substratum characteristics.				Remarks
	A	B	C	D	
I	20 Gravel	50 Gravel	69 Gravel and sand	170 Sand silt	Oil, raw sewage, and black sludge; no shrimp
II	0 Sand	100 Sand	150 Sand	250 Sand	Some large rocks; no shrimp
III	0 Gravel	50 Gravel	450 Sandy mud	--	Shrimp present
IV	20 Sand, gravel, and rocks	100 Gravel; clam bed*	250 Sandy mud	--	A very clean beach; shrimp present
V	0 Sand	50 Sand	250 Sandy mud	--	Shrimp present
VI	0 Gravel and rocks	100 Gravel and rocks; clam bed*	250 Sand	--	This site used by clam diggers

* Little-neck clams

In the laboratory, the core samples were washed by decanting to separate the organisms from the sand. The decanted water was then passed through 40-mesh and 100-mesh screens. Before discarding the sand, two aliquants were examined for the presence of small clams, ostracods, and other organisms of high specific gravity. The screenings were examined under a dissecting microscope, and the included organisms were identified and counted. This same procedure was used, also, for analyzing the square-foot samples. Without prior processing, the piling samples were examined under a dissecting microscope and the organisms identified and counted.

RESULTS

Results from the sediment samples collected in Everett Harbor on May 16, 1962, are tabulated in Table 26-2. These data are divided into three groups as dictated by the area from which they were collected (see Figure 26-1 for area limits). Note the near-complete absence of organisms in Area A, the Capitella at Stations 5 and 9 being the only life found. These data describe a biologically unproductive area, most likely caused by the burying, suffocating effects and the toxic products of anaerobic decomposition of the heavy sludge deposit in this part of the Harbor. Conditions improve, somewhat, at the entrance to the Harbor where moderate numbers of organisms appear at Stations 10 through 16. These are predominantly Capitella (segmented worms), with a few nematodes at Stations 10, 11, and 14, and a few scavenging amphipods (crustaceans) at Stations 11, 12, and 14. In spite of the appearance of organisms at these stations, some accumulation of sludge is

TABLE 26-2. Results from the sediment samples collected in Everett Harbor on May 16, 1962.

Area	Station	Number of Each Kind of Organism/Sample			Total Number of Organisms Per Sample	Kinds Per Sample	Percent Volatile Solids in Sediment
		Segmented[a] Worms	Nematodes	Crustaceans[b]			
A	1				0	0	25
	2				0	0	33
	3				0	0	34
	4				0	0	32
	5	12			12	1	40
	6				0	0	36
	7				0	0	54
	8				0	0	18
	9	8			8	1	--
Harbor Entrance	10	122	6		128	2	20
	11	282	4	22	308	3	16
	12	252		4	256	2	19
	13	268			268	1	--
	14	316	5	8	329	3	15
	15	308			308	1	11
	16	21			21	1	22
B	17	1,172			1,172	1	--
	18	534	46	2	582	3	22
	19	1,120	8		1,128	2	36
	20	26		1,084	1,110	2	12

[a] Capitella sp., a sludge-inhabiting worm, was the dominant form found.
[b] Almost all were amphipods, with Gammaridea being dominant.

indicated by the low population diversity and the predominance of the sludge-inhabiting forms. Conditions again change in Area B, in the vicinity of the Weyerhaeuser mill, where very high numbers of either Capitella (segmented worms) or Gammeridae (crustaceans) are found. Again the absence of population diversity and predominance of sludge-inhabiting forms indicate heavy sludge deposits. Toxic conditions are not indicated, however, since large numbers of organisms are present.

Results from the sediment samples collected outside of Everett Harbor during May 22-24, 1962, are tabulated in Table 26-3. As in the previous table, these data are grouped by area (see Figure 26-2A for area limits). Although some differences are seen among the benthic community structure and sediment volatile solids of each of the three areas, the important features of these data are that the benthic communities outside of the Harbor tend (1) to be more diverse; (2) to include mollusks, often in dominant numbers; and (3) to be of moderate population density; that is, neither very low or very high numbers of organisms per sample. These features are most apparent in Areas D and E where the absence of sludge is indicated by the moderate to low percentages of volatile solids found in the sediments collected. The benthic fauna of Area C more closely compares with that of the Harbor Entrance Area (Table 26-2). Field descriptions of the samples taken in Area C showed significant amounts of wood fiber, tideland odors, and dark color, all of which evidence some accumulation of sludge but less than occurs in Areas A and B of the Harbor.

TABLE 26-3. Results from the sediment samples collected in Port Gardner during May 22-24, 1962.

Area	Station	Numbers of Each Kind of Organism/Sample				Total Number of Organisms Per Sample	Kinds per Sample	Percent Volatile Solids in Sediment
		Segmented Worms[a]	Crustaceans[a]	Mollusks[a]	Other			
C	1	78				78	1	3.7
	2	570	1			571	2	8.5
	3	18				18	1	--
	4	78				78	1	10.3
D	5	12		6		18	2	8.2
	6	12		108		120	2	8.2
	7	6		30		36	2	9.7
	8	78	12	84		174	3	8.7
	9	6	6	90		102	3	9.1
	10	18		30		48	2	7.6
	11	60	6	60		126	3	--
E	12	30		138		168	2	3.5
	13	60	12	138		210	3	2.2
	14	156		102	6	264	3	2.0
	15	78		156		234	2	2.6
	16	72	6	30		108	3	1.9

[a] Several species represented in this group; hence, group diversity was evident.

Results from the square-foot substratum samples collected along the Port Gardner shoreline are given in Table 26-4. Note, in the bottom part of this table, that the diversity (kinds) and density (numbers) of the population at Station I are lower than observed at the other four stations (the low diversity at Station V as compared with that at adjacent stations, appears to be the influence of the very clean sand and absence of rocks or gravel at this station). This difference in community structure at Station I most likely is caused by the sludge, oil, and raw sewage found on and in the substrata at this Harbor station.

Results from the core samples collected during the same survey are tabulated in Table 26-5. The same features are noted; the population diversity and density at Station I are lower than respective values at the other stations. As above, these two results evidence the deleterious biological effects of the sludge and wastes commonly found on the beaches and intertidal areas of Everett Harbor.

In Table 26-6 are shown the results from the piling samples taken along the Port Gardner shoreline. These data show the definite trends of increasing population diversity and increasing population density with increasing distance from the points of waste discharge in and immediately south of (the deep-water diffuser) Everett Harbor. Important components of these trends are increasing numbers and kinds of crustaceans and mollusks, and increasing numbers of nematodes with increasing distance. Conversely, the numbers of segmented worms decline. Since sludge and waste deposits would not influence piling-

TABLE 26-4. Results from the square-foot substratum samples collected on the Port Gardner shoreline during May 22-24, 1962

Kinds	Number of Organisms per Square Foot at Each Station[a]					
	I	II	III	IV	V	VI
Algae			pr.[b]	pr.		pr.
Segmented Worms	20	312	8	42	201	96
Nematodes			1	6		1
Crustaceans						
Amphipod-Isopod	8	15	20	121	6	347
Shrimp-Crab		3	1	4	1	8
Barnacle	< 1	252	41	814		561
Mollusks						
Mussel	< 1	< 1	6	29		69
Clam			8	3	3	11
Snail	< 1	< 1		< 1		
Other						2
Total Kinds	5	6	8	9	4	9
Total Number/Square Foot	29	583	85	1,020	211	1,095

---

a/ Average of the 3 or 4 samples collected at each station

b/ Present

TABLE 26-5. Results from the core samples collected on the Port Gardner shoreline during May 22-24, 1962

	Number of Organisms per Square Foot at Each Station[a]					
Kinds	I	II	III	IV	V	VI
Algae		pr.[b]		pr.		pr.
Segmented Worms	710	4,354	5,030	2,015	6,782	3,121
Nematodes	228	10,809	517	2,376	8,588	2,916
Crustaceans						
Copepod-Ostracod		6		24		1,700
Amphipod-Isopod	12	18	48	513	48	754
Shrimp-Crab					12	433
Barnacle		349		40		
Mollusks						
Mussel		6	12			
Clam				8		32
Other						24
Total Kinds	3	7	4	7	4	8
Total Number/Square Foot	950	15,542	5,607	4,976	15,430	8,980

[a] Average of the 2 or 4 samples collected at each station
[b] Present

TABLE 26-6. Results from the piling samples collected on the Port Gardner shoreline during May 22-24, 1962.

Kinds	Number of Organisms per Square Foot				
	I	II	III	IV[a]	V-VI[b]
Green Algae					abund.
Segmented Worms	166			19	5
Nematodes			2	10	51
Crustaceans					
Amphipod-Isopod	2	11	861	145	161
Barnacle	305	929	5,436	2,675	2,065
Other					7
Mollusks					
Mussel		3	109	639	976
Total Kinds	3	3	4	5	7
Total Number/Square Foot	473	943	6,408	3,488	3,265

---

[a] Average of the 2 samples collected
[b] Average of the 4 samples collected

sample results, these trends must be associated with improving water quality with increasing distance from the Harbor. That water quality does so improve is shown by decreasing SWL concentrations toward Elliot Point (see Figure 24-6).

The same trends of increasing population diversity, population density, and numbers of crustaceans, mollusks, and nematodes are apparent in the square-foot and core-sample data of Tables 26-4 and 26-5, but these trends are partially obscured by the effects of substratum type on the community structure. Therefore, with the support of the piling-sample data, it is evident that the intertidal community of the Port Gardner shoreline also is affected by water quality, in addition to the sludge effect noted at Station I.

DISCUSSION

The above results describe two pollutional effects caused by the wastes discharged by the Scott and Weyerhaeuser mills. Sludge deposits formed by waste solids greatly inhibit the sustentation of natural benthic communities in Everett Harbor and contiguous waters. In the upper part of the Harbor, virtually no benthic life exists, whereas, in the vicinity of the Weyerhaeuser mill, an abnormally dense but non-diverse population of worms and amphipods prevails. In the Harbor entrance area and southward to the vicinity of the deep-water diffuser, lesser but detectable damage to benthic life is distinguished by lower population diversity and density than describe bottom communities found further out in Port Gardner. Intertidal marine life also is affected in the same manner; sludge and waste accumulations found on Harbor beaches serve to diminish community diversity and density.

Secondly, mill wastes dispersed in the surface waters of Port Gardner have an adverse, probably toxic, effect on intertidal organisms. Greater numbers of mussels, clams, barnacles, and certain other animals occur in areas further removed from the points of waste discharge. That intertidal organisms do suffer such toxic effects is supported by results elsewhere in this report that demonstrate the toxicity of pulping wastes to oyster larvae, English sole eggs, juvenile salmon, and other marine forms.

Alleviation of the damage to benthic life in Everett Harbor and contiguous area will require the elimination of existing sludge deposits and the prevention of future sludge accumulation in these waters.

27. OYSTER LARVAE

As in the Bellingham-Anacortes area, planktonic early-life stages of a variety of marine animals are found in the Everett area. Since these planktonic forms are usually more susceptible to alterations of the environment than are later life stages, the greatest damage to a species is likely to occur during the egg or larval stages.

Commercial oyster production formerly was practiced in Port Susan, but no commercial oyster grounds are present now. The beaches between Everett and Mukilteo in past years supported a sport fishery for clams; now clam digging is restricted to the immediate vicinity of Mukilteo. However, other beaches in the Everett area (*e.g.*, Gedney Island) still provide a sport fishery for clams.

To assess the potential damage to shellfishes and other forms in the Everett area, the Project conducted two investigations using Pacific oyster larvae bioassays: (1) a field-sample oyster-larva response study; and (2) a waste-sample oyster-larva response study.

STUDIES

The field-sample oyster-larva study in the Everett area was conducted at ten stations (Figure 27-1). Surface water samples were collected at the stations at monthly intervals between May 1963 and August 1964; and additional samples were taken during the periods of July 6-9 and November 16-30, 1964, to evaluate water-quality changes during closures or reduced operation of the Scott and Weyerhaeuser

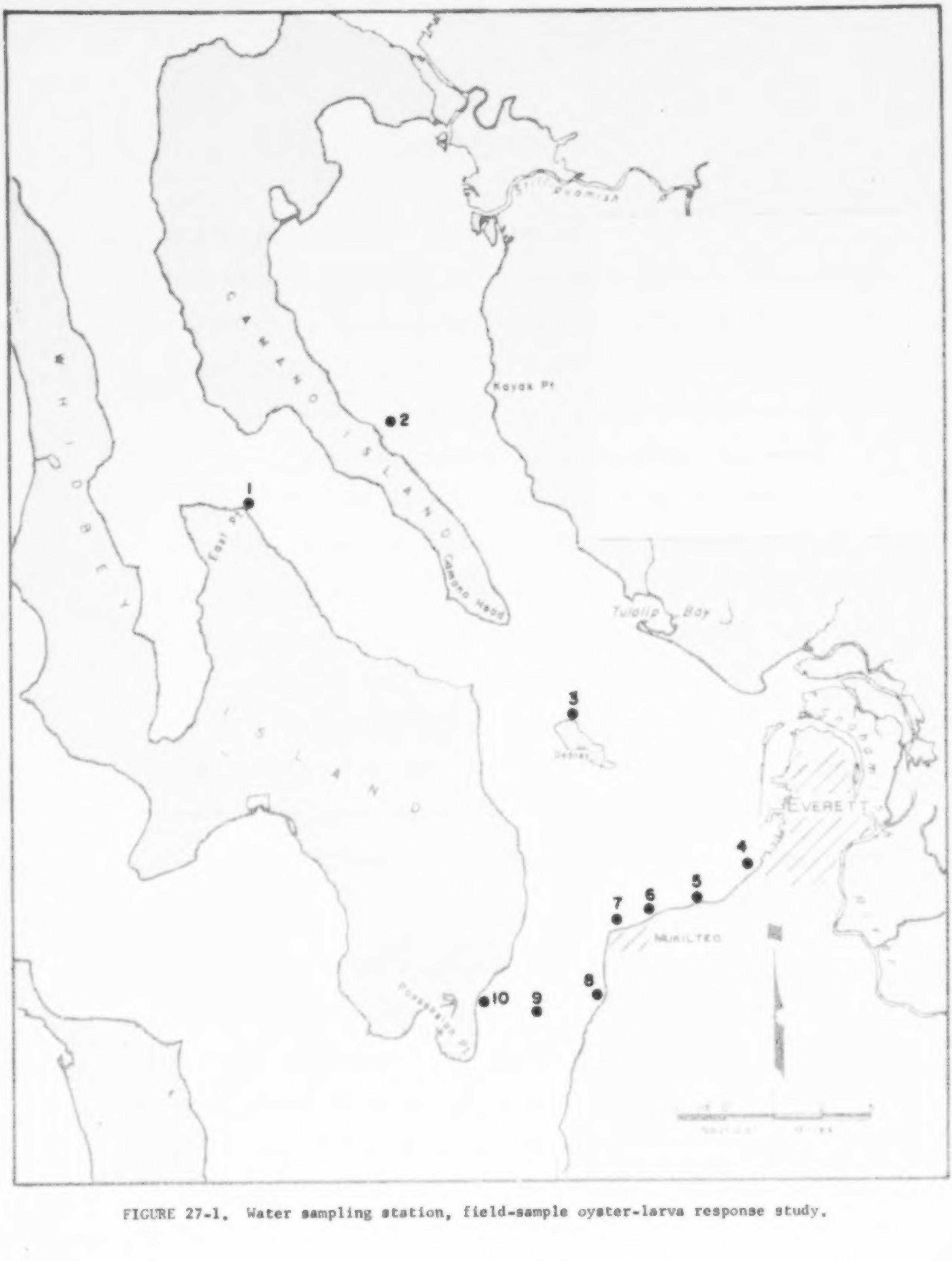

Stillaguamish
CAMANO ISLAND
WHIDBEY ISLAND
Kayak Pt
East Pt
Camano Head
Tulalip Bay
Gedney
EVERETT
MUKILTEO
Possession Pt
1
2
3
4
5
6
7
8
9
10
Nautical Miles

FIGURE 27-1. Water sampling station, field-sample oyster-larva response study.

mills. Supplementary samples were collected on July 13, 1965, as checks on water quality and to provide additional "overlap" sampling.

The waste-sample oyster-larva response study was conducted on 24-hour composite samples of in-plant wastes (1) from four waste sewers at the Scott pulp and paper mills on August 4, 1964; (2) from four waste sewers of the Weyerhaeuser sulfite pulp mill on September 15, 1964; and (3) from the Simpson Lee kraft and paper mill on September 15, 1964; and (4) from the Weyerhaeuser kraft mill, after about six hours' detention in a holding lagoon, on January 19, 1965.

All bioassays and associated laboratory analyses for both studies were performed or supervised by Charles E. Woelke of the Washington State Shellfish Laboratory staff.

METHODS

The methods and procedures used in these studies are described in Section 11.

RESULTS

Results of Field-Sample Study. The results of the oyster-larva bioassays for the Everett area are presented and discussed by Dr. G. J. Paulik, Biometrician, University of Washington School of Fisheries, in a final report (1966a). Descriptions of the statistical tests used are described by Paulik in four interim reports (1963, 1964, 1965a, and 1965b) and in the final report (op. cit.).

Bioassay-response results of the 17-month study are presented in Table 27-1. These results are based on data derived after removal of (1) samples having salinities of 20°/oo, or less; (2) samples bioassayed during the 1963-64 winter period; and (3) samples collected early on July 6, 1964--before waste flows began again after the July 4 holiday--and on November 16 and 23, 1964, when, because of a labor strike, the Scott mill was not operating and the Weyerhaeuser mill was operating at about 60% of the normal level. The rationale for the removal of these samples is given in Section 11. For the Everett area, these exclusions restrict the usable samples to essentially the spring and summer periods.

Therefore, Table 27-1 and the discussion below consider only those data derived from (1) samples not influenced by low salinities or test eggs of questionable quality and (2) from those samples taken during normal mill operations which reflect the usual ranges of water quality and environmental conditions found in the study area.

Column 3 of Table 27-1 gives the response measure "mean percent-abnormal" for each station. These values together with the mean SWL values, Column 5, are presented (rounded) in Figure 27-2. In spite of the fact that the samples were taken over a wide variety of meteorological and hydrographic conditions, there are clear-cut differences between the individual stations.

In Table 27-1, a definite relationship between mean percent abnormal and mean SWL concentration is seen--mean percent-abnormals increase with increases in SWL concentration. This relationship is evident as well in Figure 27-2 where it may be seen also that percent

TABLE 27-1. Summary of results from the field sample oyster-larva response study in the Everett area, May 1963 - July 1965. Data from samples with salinities of 20°/oo or less and samples collected during the 1963-64 winter period (October through March inclusive) and on July 6, 1964, and on November 16 and 23, 1964, are omitted.

Station Number (1)	Number of Field Samples (2)	Mean Percent Abnormal (3)	Mean Percent Net Risk (4)	Mean SWL Conc. (ppm) (5)	Mean Salinity (°/oo) (6)	Mean Intra-Sample Variance of Percent Abnormal (7)	Inter-Sample Standard Error of Mean Percent Abnormal (8)	Standard Deviation of SWL Conc. (9)	Standard Deviation of Percent Net Risk (10)
1	8	3.62	2.54	5.9	25.03	2.46	2.03	2.1	6.0989
2	5	2.65	2.14	7.4	23.83	7.82	1.04	1.7	2.4506
3	8	9.87	8.97	9.5	24.03	32.89	7.24	2.7	20.4812
4	6	79.11	78.92	76.7	23.74	4.89	15.97	44.2	39.4616
5	6	63.30	62.90	31.1	24.07	9.90	19.05	22.1	47.1671
6	7	66.23	65.99	21.3	23.82	2.86	16.75	14.0	44.6027
7	8	48.53	48.03	15.8	24.52	361.97	12.66	7.0	35.9764
8	5	6.35	5.27	6.5	26.06	20.16	3.71	3.0	7.1035
9	4	13.27	12.19	9.1	21.00	106.07	6.48	2.6	11.9051
10	9	13.09	12.25	9.6	23.04	43.73	5.43	3.4	16.1557

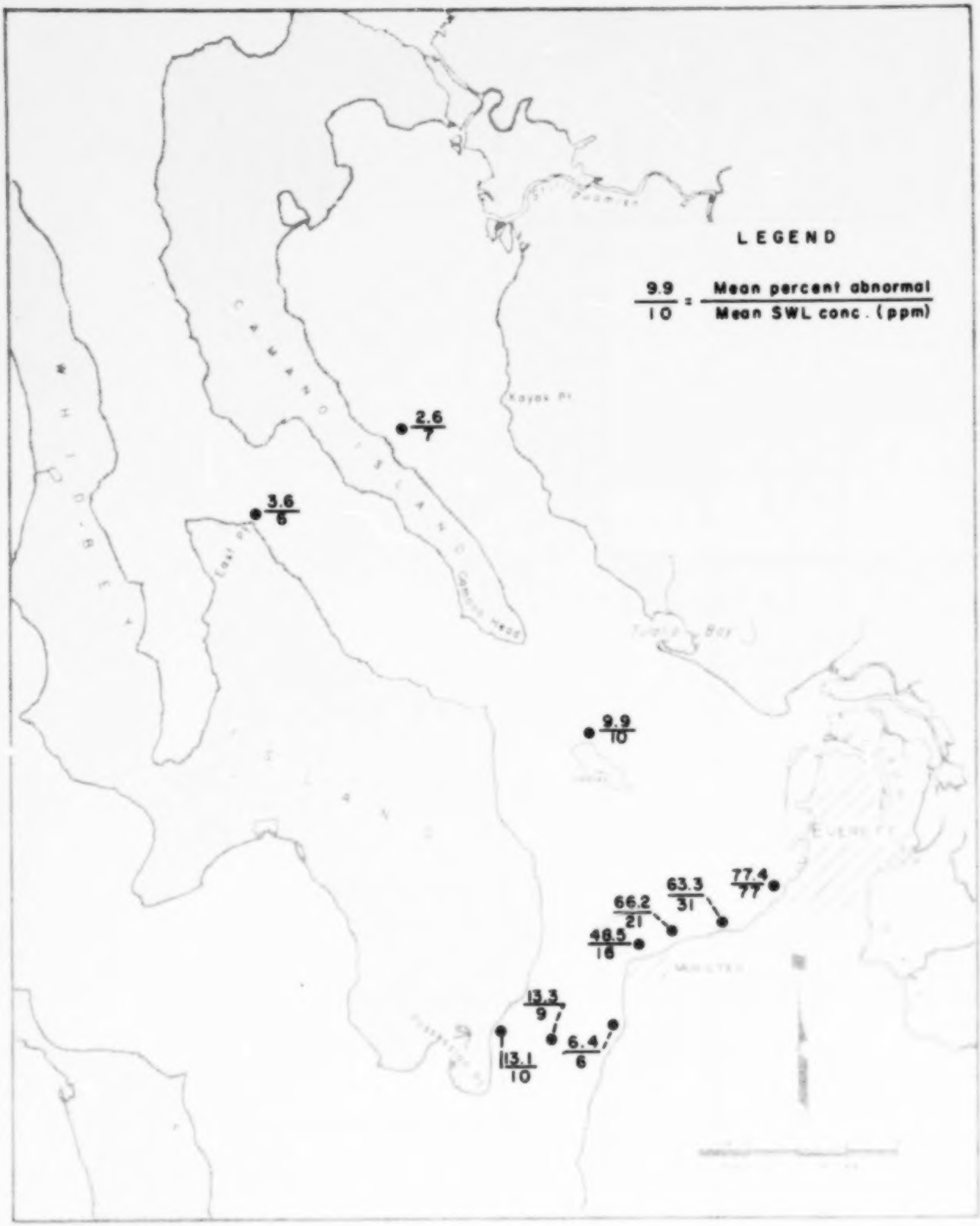

LEGEND
9.9 / 10 = Mean percent abnormal / Mean SWL conc. (ppm)
CAMANO ISLAND
WHIDBEY ISLAND
Kayak Pt
East Pt
Camano Head
Tulalip Bay
EVERETT
MUKILTEO
2.6 / 7
3.6 / 6
9.9 / 10
77.4 / 77
63.3 / 31
66.2 / 21
46.5 / 16
13.3 / 9
6.4 / 6
13.1 / 10

FIGURE 27-2. Mean percent oyster-larva abnormality and mean SWL concentration at each field-sample station in the Everett area: field-sample oyster-larva response study, May 1963 through August 1965 (See Table 27-1 for description of data removed).

abnormal values increase with decreasing distance from the primary waste discharge point of both mills, the diffuser near Station 4. It is evident that pulping wastes affect oyster-larva development and that the sources of these damaging wastes are the Scott and Weyerhaeuser mills.

Larval Abnormality vs. SWL Concentration. Figure 27-3 shows the relationship between the percent of abnormal larvae and the SWL concentration. The method of deriving this logistic curve is given in Section 11. Note that larval abnormality begins to increase very rapidly at SWL concentrations of about 6 ppm and that near-100% abnormality is reached at about 40 ppm. When this curve is compared to the curve of the Bellingham-Anacortes area (Section 11) and that of the Port Angeles area (Section 37), it is evident that the waters in the Everett area show a higher toxicity at the lower SWL levels than those in the other two study areas.

Larval Abnormality in Controls. In Section 11, a comparison was made between laboratory controls, carry-along controls, and "field controls." The latter were arbitrarily defined as samples that (1) had salinities greater than $20^{\circ}/oo$, (2) were not collected during the 1963-64 winter period, and (3) had SWL concentrations of 2.0 ppm or less.

When these restrictions are applied to samples from the Everett study area, all but one of the samples are excluded by the third criterion (SWL values be 2 ppm or less) and the one sample had less than $20^{\circ}/oo$ salinity. If the SWL requirement is relaxed to include all samples with SWL values greater than 2 but not more than 4, only

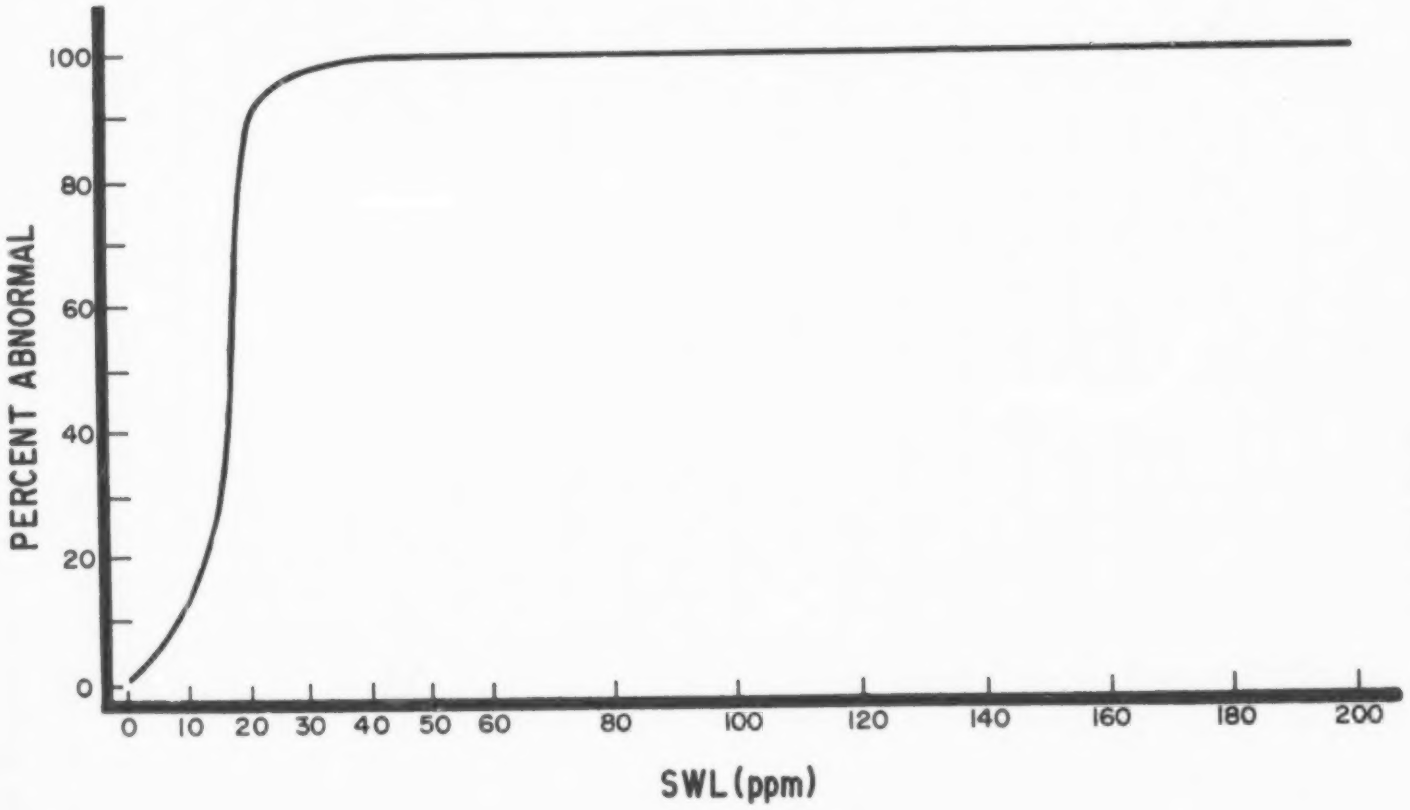


FIGURE 27-3. Percent larval abnormality vs. SWL, for the Everett area.

five samples from the Everett area fall into this category. For these five samples, the mean percent abnormals is 2.28 and that of controls is 1.47. These values are indistinguishable both practically and statistically, but the very small number of samples involved here requires that consideration of field-control samples for determination of non-harmful conditions must be based on data from the Bellingham-Anacortes area (Section 11) and the Port Angeles area (Section 37).

Larval Abnormality During Mill Closure. While the labor strike of November 12-26, 1964, stopped all production at the Scott mill, the Weyerhaeuser mill continued production at about 60% of capacity. Consequently, while SWL concentrations at some stations dropped to levels below the overall mean for those stations, the concentrations remained at or about the usual levels at other stations. For example, an oceanographic cruise on November 19, seven days after the strike began, revealed surface SWL values about the same or slightly greater than the 1962-63 average for the same transect. At Stations 3 through 7 of this study, SWL concentrations declined generally but were still 14 to 18 ppm and resulted in 71% to 100% abnormals. With reference to the logistic curve (Figure 27-3), note that SWL levels would have to be reduced to about 10 ppm before marked changes in the response measure, percent abnormals, would occur.

Although the July 4 holiday shutdown was of comparatively short duration, essentially all production was halted for about 3 days. When the results of usable samples collected the morning of July 6 are compared to the overall mean values for the same stations (Table 27-2), the improvement resulting from even limited cessation of wastes can be seen (salinities less than 20°/oo preclude comparisons with all but two samples collected June 23 and July 9, 1964).

TABLE 27-2. Percent-abnormal and SWL values for samples with salinities >20°/oo collected on July 6, 1964 and overall mean values for the same stations--Everett study area.

	SWL (ppm)		% Abnormal	
Station	July 6	Mean	July 6	Mean
1	4	6	1.0	3.6
3	4	10	1.0	9.9
7	5	16	2.3	48.5
8	4	6	2.9	6.4
10	4	10	2.5	13.1

Results of the Waste-Sample Study. Results of this study, given below, are fully presented and discussed by Woelke in a report to the Project (1965 unpublished). The descriptions of methods used and data treatment are given in Section 11. Briefly, 24-hour-composite samples of waste streams were serially diluted with fresh unpolluted seawater and were bioassayed with oyster larvae. The response measures, percent abnormals, of the various dilutions of a waste were plotted on probit paper against the appropriate dilution ratios and SWL concentrations; from the line of best fit, dilution ratios and SWL values for the 0, 20, 50, and 100% abnormal levels were determined. These data are given in Table 27-3.

TABLE 27-3. Dilution ratios and concentrations of waste dilutions which produce 0, 20, 50, and 100% abnormal oyster larvae for wastes collected from sources in the Everett area.

Waste Stream	No Abnormality		20% Abnormal		50% Abnormal		100% Abnormal		Mean % Abnormal in Laboratory Control
	SWL (ppm)	Dilution Ratio	SWL (ppm)	Dilution Ratio	SWL (ppm)	Dilution Ratio	SWL (ppm)	Dilution Ratio	
Scott sulfite mill									
Digester	3	1:100,000	17.5	1:11,500	28	1:7,200	104	1:2,000	.05
Pulp washing and bleach plant	1	1:1,000	9.2	1:170	11.5	1:145	75	1:20	.05
Scott paper mill									
Whitewater	2	1:20	> 2	>1:10	> 2	> 1:10	> 2	>1:10	.05
Paper machine	>0	>1:10	> 0	>1:10	>0	>1:10	>0	>1:10	.05
Weyerhaeuser sulfite mill									
Digester	0	1:100,000	1.4	1:7,800	2.4	1:5,400	10	1:2,000	.98
Combined digester and caustic extractor	0	1:100,000	1.3	1:7,900	2.1	1:5,450	7	1:2,000	.98
Combined pulp washing, screen room, settled barker wastes, and saltwater cooling water.	0	1:100,000	9.1	1:550	11.5	1:475	22	1:200	.98
Bleach plant	1	1:2,000	< 1	1:690	< 1	1:500	1	1:200	.98
Caustic extractor	0	1:200	1.5	1:65	2.1	1:47	5	1:20	.98
Weyerhaeuser kraft mill									
Total waste flow (after ca. 6-hour lagoon detention).	-*	1:1,000	-	1:700	-	1:430	-	1:100	1.79
Simpson Lee kraft and paper mill									
Total waste flow	0	1:10,000	5.7	1:68	7.8	1:48	17	1:20	.98

* Not available.

Note that when the data are arrayed by dilution ratio, SWL values do not show any particular pattern, although the most toxic wastes are associated with the pulp-cooking process. This suggests that no single toxic component exists in the waste samples, or if one does exist, it is not being measured by the Pearl-Benson Index test for SWL. Note also that many of these wastes are toxic (i.e., 20% abnormality) at or below the SWL level generally accepted as "background." This implies that the absence of high SWL levels in areas receiving pulp mill wastes does not rule out the pulp mill as a source of material causing adverse biological responses.

To further illustrate the toxic effects of the waste streams considered in Table 27-3, the amounts of dilution water required to reduce the toxicity of each to non-harmful levels (no larval abnormality) were computed and are shown in Table 27-4. It may be seen that very large amounts of dilution water are required for digester wastes and combined kraft and paper mill wastes and considerable amounts are needed for bleach wastes and lagooned kraft mill wastes.

The strong digester wastes of the Scott pulp mill and the strong digester wastes and caustic-extract wastes of the Weyerhaeuser pulp mill are discharged through the 300- to 345-foot deep diffuser line into Port Gardner (see Section 23) where considerable dilution does occur. However, the high mean percent abnormals seen at Stations 3 through 10 (Figure 27-2) are evidence of the insufficient dilution and widespread occurrence of these strong wastes, even at the surface.

TABLE 27-4. Dilution water required to reduce the toxicity of Everett area wastes to zero (have no effect on oyster-larva development).

Waste Stream	Waste Flow* (mgd)	Dilution Water Required for no Abnormality (cfs)**
Scott Sulfite Mill		
Digester	13.15	2,034,600
Pulp washing and bleach plant	40.32	62,400
Scott Paper Mill		
Whitewater	3.49	108
Paper machine	8.40	65
Weyerhaeuser Sulfite Mill		
Digester	4.50	696,000
Combined digester and caustic extractor	9.50	1,470,000
Combined pulp washing, screen room, settled barker wastes, and saltwater cooling water	7.80	24,140
Bleach plant	8.00	24,760
Caustic extractor	5.00	1,550
Weyerhaeuser Kraft Mill		
Total waste flow	24.96	38,620
Simpson Lee Kraft and Paper Mill		
Total waste flow	9.82***	152,000

* Average flow rate, in millions of gallons per day, for period when samples were collected.

** Cubic feet per second (one cfs is equal to 643,317 gallons per day).

*** Average flow during in-plant survey of March 9-11, 1964.

DISCUSSION

The effect of SWL on the various shellfish adults and larvae tested thus far is discussed in Section 10. It is noted that the larvae of these animals are particularly sensitive and respond to very similar, and low, levels of SWL.

While no commercial oyster grounds remain in the Everett area, a substantial but much reduced sport fishery for clams exists. Protection of this resource will require reduction of surface SWL levels in Port Gardner and contiguous waters to a maximum of 10 ppm. Even at this level, some damage to the resource will occur (Figure 27-3), since the wastes here exhibit greater toxicity than elsewhere.

Attention is called to the amounts of dilution water required to reduce the strong sulfite pulping wastes (Table 27-3) to non-damaging levels (Table 27-4). Although these strong wastes are dispersed through a deep diffuser now (see Section 24), the consistently high levels of oyster-larva abnormalities at Stations 4 through 7 are evidence of the ineffectiveness of dilution. Even at Station 3 (Gedney Island), 50% oyster-larva abnormality is exceeded in one-third of the usable samples.

Clearly, treatment of the strong pulping wastes before discharge through the diffuser is necessary to protect the shellfish resource in the Everett area.

28. FLATFISH EGGS

Other planktonic early-life stages occurring in the Everett study area are those of the several species of flounders (mostly Pleuronectidae) common to Puget Sound. The commercially most important of these is the English sole (Ward, Robison, & Palmen; 1964). These fish tend to seek out and spawn in embayments, such as Port Gardner and Port Susan. When fertilized, the eggs of these fishes float, and subsequent embryonic and larval development takes place in the near-surface waters. It is in this surface zone, however, that the sensitive early-life stages are most apt to encounter dilute concentrations of pulp mill wastes, and there is evidence that they are injured by the toxicity of these wastes. For this reason, English sole egg studies were conducted to determine: (1) the distribution and abundance of English sole eggs in the Everett study area, and the associated water quality; and (2) the relationship between the injury caused and the strength of the dispersed wastes.

STUDIES

English Sole Egg Distribution Study. The English sole egg distribution study in the Everett-Port Gardner area was performed in conjunction with and in the same manner as the English sole egg distribution study in the Bellingham area described in Section 12. Briefly, fish eggs and associated water quality were sampled at 8 stations in the Everett Harbor-Port Gardner area (Figure 28-1)

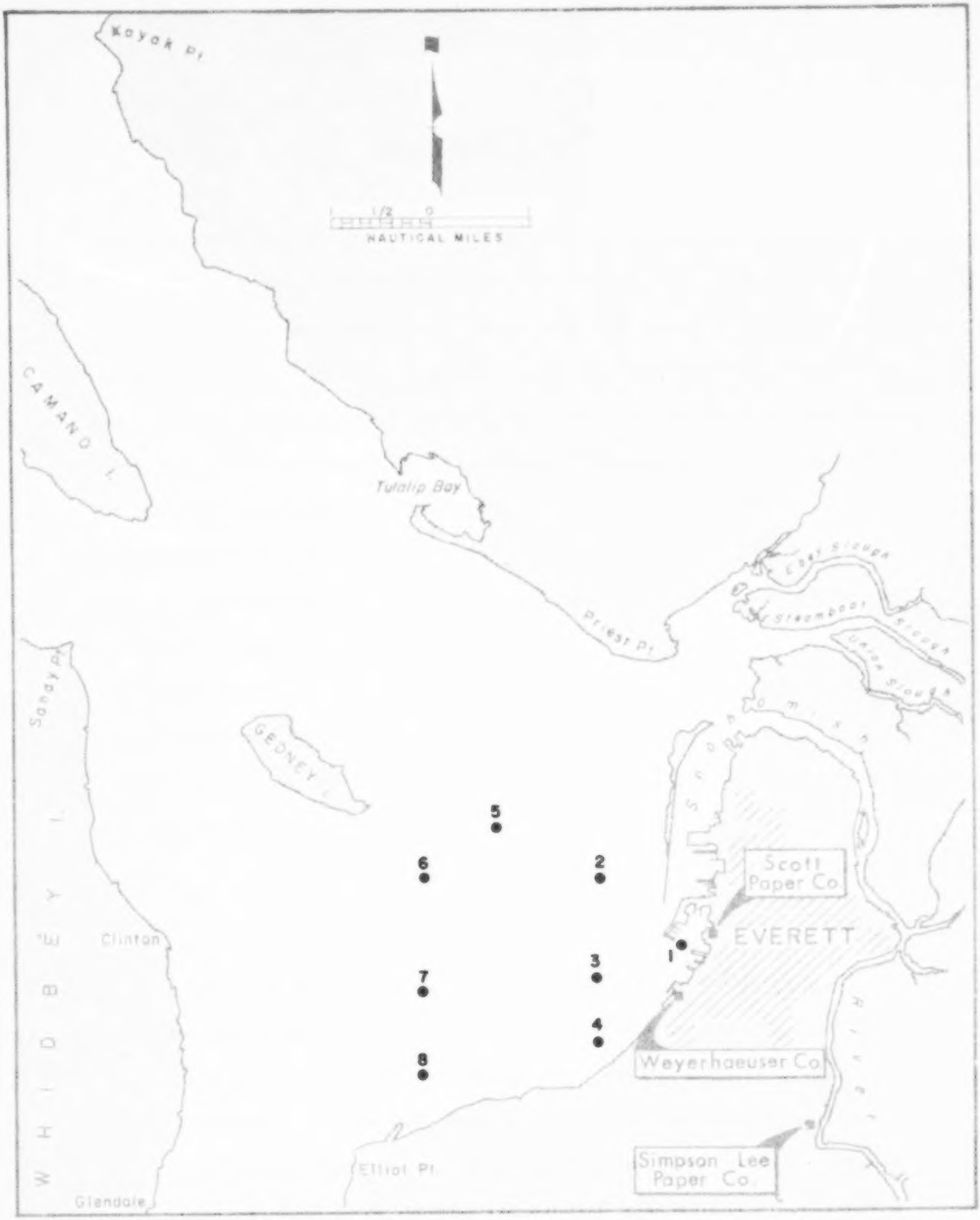

Kayak Pt
1/2
0
NAUTICAL MILES
CAMANO I.
Tulalip Bay
Ebey Slough
Steamboat Slough
Union Slough
Priest Pt
Sandy Pt
GEDNEY I.
Snohomish
5
6
2
Scott Paper Co
EVERETT
Clinton
1
3
7
4
8
Weyerhaeuser Co
River
WHIDBEY I.
Simpson Lee Paper Co.
Elliot Pt
Glendale

FIGURE 28-1. Station locations in the Everett area at which flatfish eggs were collected and water quality was determined.

at depths of 1, 17, and 33 feet on the four occasions during January through March, 1966. The English sole egg fraction was removed from the preserved plankton sample and measured volumetrically.

It was found that significant numbers of English sole eggs were present in the surface waters of Everett Harbor and Port Gardner during the peak of the reproductive season (Table 28-1). It is important to note that large numbers of eggs occur (1) in waters with high SWL concentration, and (2) in waters of reduced salinity with specific gravity less than that of the eggs, which is 1.022.

English Sole Bioassay Study. This study is the one conducted at Friday Harbor from January through April 1965 and is discussed in detail in Section 12. Briefly summarizing the results of that study, it was found that SWL concentrations of 14 ppm increase egg mortality 500 percent over controls, hatch failure 215 percent, and failure of the eggs to develop into normal larvae 65 percent. Concentrations of SWL above 180 ppm virtually preclude development of any normal larvae.

DISCUSSION

The findings of the distribution study demonstrate that large numbers of English sole eggs are spawned into areas polluted by SWL and that they develop in the surface layers where the highest concentrations of SWL occur.

It is readily seen in Table 28-1 that SWL concentrations as high as 80 ppm exist in regions of maximum egg concentration. If the English sole potential of the Everett Harbor-Port Gardner area is not to be damaged, the critical tolerance levels determined by the

TABLE 28-1. Flatfish egg distribution in the Everett area; March 3, 1966

Station	Depth (ft.)	Temp. (°C)	Salinity (°/oo)	Specific Gravity	SWL (ppm)	Volume of Eggs (ml)*
1	1	7.5	23.1	1.0181	151	< 0.1
	17	7.8	28.0	1.0218	79	1.5
	33	7.8	28.3	1.0221	81	1.0
2	1	5.9	15.0	1.0119	27	< 0.1
	17	7.0	22.2	1.0174	39	3.0
	33	7.7	27.5	1.0215	71	0.3
3	1	7.0	22.0	1.0172	42	1.0
	17	7.8	23.1	1.0180	80	5.8
	33	7.8	28.5	1.0222	49	2.1
4	1	6.9	21.9	1.0172	45	3.6
	17	7.5	26.3	1.0206	35	1.8
	33	7.7	28.3	1.0221	80	3.7
5	1	6.4	22.1	1.0174	18	< 0.1
	17	7.8	27.1	1.0211	17	0.1
	33	8.0	28.2	1.0220	39	0.6
6	1	6.5	22.5	1.0177	17	0.1
	17	6.7	25.0	1.0196	17	0.4
	33	7.8	27.8	1.0217	39	0.1
7	1	6.6	21.7	1.0171	27	< 0.1
	17	7.0	24.6	1.0193	19	< 0.1
	33	7.4	27.3	1.0213	29	0.6
8	1	6.6	21.3	1.0167	29	< 0.1
	17	7.5	26.0	1.0203	15	0.5
	33	7.7	28.0	1.0219	27	1.1

* One ml contains approximately 1,000-1,200 fertilized English sole eggs.

bioassay study must not be exceeded. It is therefore recommended, to afford optimal conditions for English sole egg development, that the Scott mill and the Weyerhaeuser mill put into operation appropriate abatement measures to reduce SWL concentrations in the surface waters to less than 14 ppm.

29. PLANKTON

The objectives of the plankton study in the Everett area are identical to those in the Bellingham area described in Section 13.

Ten sampling cruises were made at four- to eight-week intervals between August 1964 and July 1964, inclusive. On each cruise five stations (Figure 29-1) were occupied: Station No. 1 in the inner harbor, Station No. 2 over the end of the deep diffuser pipeline, and three others further removed from the harbor. All field work was conducted aboard the R/V HAROLD W. STREETER. The measurements and analyses made, and the methods used, were identical to those in the Bellingham area (see Section 13).

RESULTS

Data obtained from the study are summarized as mean values in Tables 29-1, 29-2, and 29-3. Note that almost all of the chemical and physical properties measured at a given depth show little significant variation among stations. The exceptions are the mean SWL concentrations which decrease with distance from the inner harbor and the very high mean oxygen consumption rate in the inner harbor (Station 1). These data describe findings in keeping with those discussed in Section 24.

Examination of the biological data (Tables 29-1, 29-2, 29-3) indicates that there is little variation in the dynamic structure of the plankton community among the various stations at a given depth.

Preceding page blank

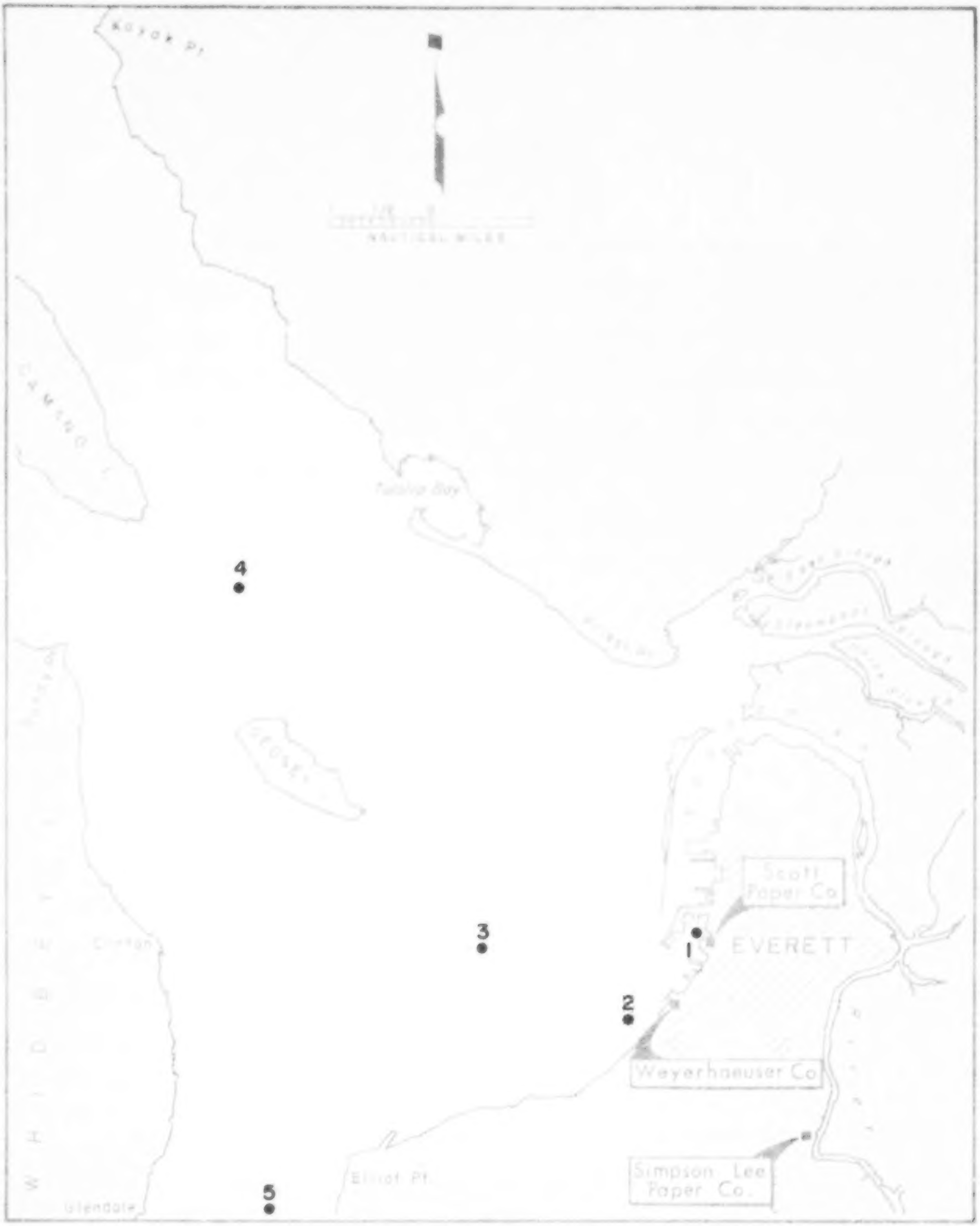

Kayak Pt.
NAUTICAL MILES
CAMANO
Tulalip Bay
4
GEDNEY
Scott Paper Co.
3
1
EVERETT
Clinton
2
Weyerhaeuser Co.
WHIDBEY
Simpson Lee Paper Co.
Elliot Pt.
5
Glendale

FIGURE 29-1. Phytoplankton productivity stations in the Everett area.

TABLE 29-1. Mean values of properties measured at the surface in the Everett area; plankton study of August 1964 - July 1965.

Property	Station 1	Station 2	Station 3	Station 4	Station 5
Temperature (°C)	10.8	9.9	10.3	10.3	10.3
Secchi Disc (m)	2.1	3.8	3.9	4.3	5.0
Salinity (°/oo)	23.0	24.1	22.0	22.8	24.5
pH	7.5	7.8	7.9	8.0	7.9
Dissolved Oxygen (mg/l)	6.6	8.6	9.4	9.9	9.7
Dissolved Oxygen (% Sat)	67	86	94	100	99
Oxygen Consumption Rate ($mgO_2/m^3/hr$)	83.1	12.4	12.6	4.2	4.1
NO_3 (microgram atoms/l)	8.9	15.5	13.6	12.7	14.3
PO_4 (microgram atoms/l)	1.0	1.2	1.0	1.0	1.1
SiO_4 (microgram atoms/l)	46.3	49.6	45.3	40.7	37.7
Sugar (mg/l)	0.7	0.2	0.7	0.5	0.5
SWL (ppm, 10% Solid Sol.)	84	25	20	14	15
Zooplankton Concentration (organisms/m^3)	- -	10,792	2,672	2,349	4,362
No. of Taxa - Zooplankton	- -	11.1	9.8	9.4	9.8
% Adults - Zooplankton	- -	61	67	65	63
Dominant Forms - Zooplankton (in rank order)	- - - -	Acartia clausi	Acartia clausi	Acartia clausi	Appendicularia
	- - - -	Corycaeus affinis	Corycaeus affinis	Appendicularia	Corycaeus affinis
	- - - -	Pseudocalanus minutus	Appendicularia	Fish Eggs	Acartia clausi
	- - - -	Appendicularia	Acartia longiremis	Corycaeus affinis	Acartia longiremis
	- - - -	Acartia longiremis	Cladocera Evadne sp.	Barnacle nauplius	Fish Eggs
Chlorophyll a (mg/m^3)	18.4	18.7	23.9	23.5	31.4
Phytoplankton Concentration (cells/l x 10^{-3})	438	450	580	219	309
No. of Taxa - Phytoplankton	5.3	2.8	3.2	3.7	3.7
Dominant Forms - Phytoplankton (in rank order)	Skeletonema	Skeletonema	Skeletonema	Skeletonema	Skeletonema
	Anacystis	Synedra	Cyclotella	Thalassiosira	Thalassiosira
	Thalassiosira	Navicula	Thalassiosira	Anacystis	Synedra
	Synedra	Thalassiosira	- -	- -	Coscinodiscus
	Chaetoceros	Coscinosira	- -	- -	- -
Phytoplankton Productivity Rate ($mgC/m^3/hr$)	9.8	53.7	48.7	27.1	72.4

TABLE 29-2. Mean values of properties measured at 7 feet in the Everett area; plankton study of August 1964 - July 1965.

Property	Station				
	1	2	3	4	5
Temperature (^{o}C)	10.2	10.0	9.9	10.0	10.1
Light Remaining (^{o}/o of surface)	9.6	22.2	22.6	22.7	30.2
Salinity (^{o}/oo)	24.1	24.0	23.5	23.9	25.1
pH	7.5	7.8	7.9	7.9	8.0
Dissolved Oxygen (mg/l)	6.7	8.6	9.3	9.9	9.4
Dissolved Oxygen (^{o}/o Sat)	67	87	94	100	96
Oxygen Consumption Rate ($mgO_2/m^3/hr$)	92.1	11.7	8.3	4.4	1.7
NO_3 (microgram atoms/l)	9.8	13.8	14.6	13.6	15.5
PO_4 (microgram atoms/l)	0.9	1.2	1.2	1.0	1.1
SiO_4 (microgram atoms/l)	46.1	45.6	45.7	39.4	41.2
Sugar (mg/l)	0.5	0.1	0.5	0.4	0.3
SWL (ppm, 10% Solid Sol.)	83	25	18	14	15
Chlorophyll a (mg/m^3)	16.0	18.8	20.2	23.4	29.5
Phytoplankton Concentration (cells/l x 10^{-3})	156	523	401	256	201
No. of Taxa - Phytoplankton	4.1	3.1	4.1	2.9	2.9
Dominant Forms - Phytoplankton (in rank order)	Skeletonema Thalassiosira Nitzschia - - - -	Skeletonema Anacystis {Thalassiosira {Navicula Synedra	Skeletonema Navicula Cyclotella Thalassiosira Amphora	Skeletonema Anacystis Thalassiosira	Skeletonema Anacystis Coscinodiscus Thalassiosira
Phytoplankton Productivity Rate ($mgC/m^3/hr$)	1.5	8.2	10.4	5.5	16.6

TABLE 29-3. Mean values of properties measured at 20 feet in the Everett area; plankton study of August 1964 - July 1964.

Property	Station 1	Station 2	Station 3	Station 4	Station 5
Temperature (^oC)	9.6	9.6	9.8	9.8	9.9
Light Remaining ($^o/o$ of surface)	1.6	4.8	4.1	4.9	7.7
Salinity ($^o/oo$)	27.8	26.9	27.1	27.2	27.7
pH	7.6	7.8	7.8	7.8	7.9
Dissolved Oxygen (mg/l)	6.2	7.8	8.0	8.1	8.1
Dissolved Oxygen ($^o/oo$ Sat)	64	80	82	83	84
Oxygen Consumption Rate ($mgO_2/m^3/hr$)	20.0	-7.1	9.3	5.2	0.3
NO_3 (microgram atoms/l)	13.2	18.3	17.4	16.3	18.4
PO_4 (microgram atoms/l)	1.3	1.6	1.5	1.5	1.4
SiO_4 (microgram atoms/l)	43.6	44.4	37.4	37.0	40.0
Sugar (mg/l)	0.5	0.3	0.2	0.1	0.6
SWL (ppm, 10% Solid Sol.)	59	18	19	17	15
Zooplankton Concentration (organisms/m^3)	- -	5,142	4,346	7,914	5,684
No. of Taxa - Zooplankton	- -	14.0	13.5	13.3	13.6
% Adults - Zooplankton	- -	51	63	70	57
Dominant Forms - Zooplankton (in rank order)	- - - - - - - - - -	Pseudocalanus minutus Corycaeus affinis Acartia clausi Acartia longiremis Oithona spinirostris	Corycaeus affinis Pseudocalanus minutus Fish Eggs Amphipod-Hyperiid Oithona similis	Oithona similis Oithona spinirostris Pseudocalanus minutus Corycaeus affinis Fish Eggs	Corycaeus affinis Pseudocalanus minutus Amphipod-Hyperiid - - - -
Chlorophyll a (mg/m^3)	18.5	18.8	26.4	30.1	30.3
Phytoplankton Concentration (cells/l x 10^{-3})	142	155	288	267	377
No. of Taxa - Phytoplankton	3.8	2.6	2.5	3.0	3.5
Dominant Forms - Phytoplankton (in rank order)	Skeletonema Anacystis Chaetoceros Cocconeis Thalassiosira	Thalassiosira Skeletonema Coscinodiscus Cyclotella - -	Skeletonema Thalassiosira {Coscinodiscus {Navicula - -	Skeletonema Thalassiosira Thalassionema - - - -	Skeletonema Thalassiosira Anacystis Navicula Cyclotella
Phytoplankton Productivity Rate ($mgC/m^3/hr$)	4.9	1.6	2.7	2.6	1.0

There is no significant difference between the annual mean values at any one station and the annual mean values at all other stations combined for the following: chlorophyll a concentration, phytoplankton concentration, number of phytoplankton taxa (diversity), zooplankton concentration, number of zooplankton taxa, and the percentage of adults making up the zooplankton. Further, the dominant organisms of both phytoplankton and zooplankton are generally the same at all stations. It is thus apparent that the structure of the plankton community is essentially the same throughout the study area, even though the raw data show considerable, but expected, seasonal variation in the numbers and kinds of plankters.

Phytoplankton productivity rate is the only biological property that exhibited significant interstation differences in annual mean values. Note in Table 29-1 that comparatively low rates of productivity were observed at the surface at Station 1 (a mean of 9.8 mg carbon fixed/m^3/hr). To evaluate the differences between these values and mean values obtained at other stations in the study area, consideration was given to information exhibited by all raw data--that conditions of low temperature and low light intensity (depth) also inhibit productivity. Accordingly, with the removal of all data collected at water temperatures less than 10°C and all data collected at the 7- and 20-feet depths, it was found that mean productivity at Station 1 was significantly lower than the associated mean value at all other stations combined.

Because average SWL concentrations are highest at Station 1 an association with productivity was suggested. Figure 29-2 was

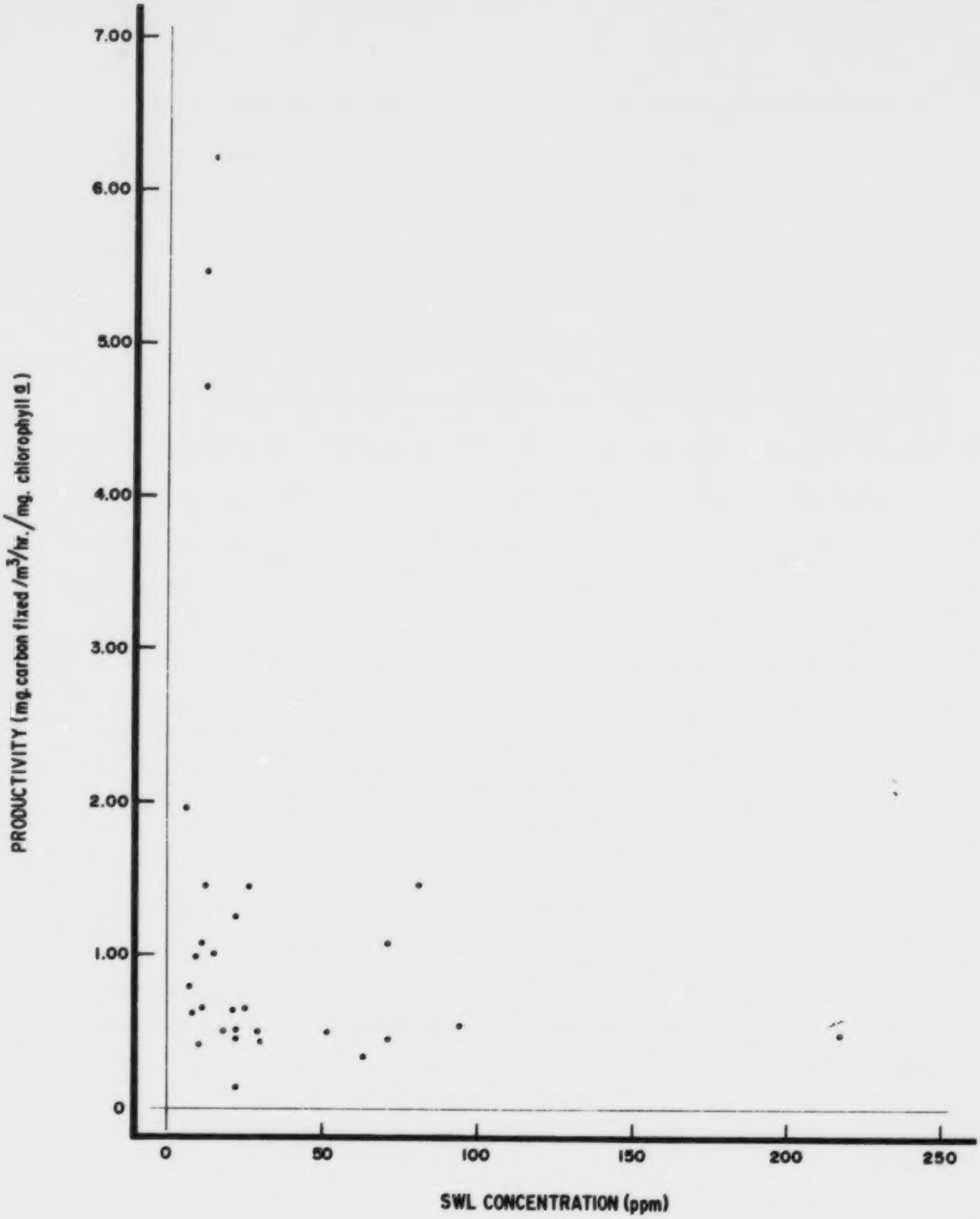


FIGURE 29-2. The relationship of phytoplankton productivity rate per mg of chlorophyll a vs. SWL concentration for samples collected at the surface at temperatures equal to or greater than 10°C in the Everett study area.

constructed using those data collected at surface stations and at temperatures equal to or greater than 10°C. To compensate for the variation found in standing crop, the values in this graph are presented as productivity rate per unit of chlorophyll a. Note that a monotonic relationship between productivity rate per mg of chlorophyll a and SWL concentration does not exist, but that a threshold effect occurs. Phytoplankton productivity begins to decline at SWL values around 30 ppm. This drop in productivity per unit of chlorophyll a is shown in a different manner in Table 29-4, where the productivity data of Figure 29-2 is summarized by groupings associated with the SWL concentration ranges of 0-50 ppm, 51-100 ppm, and 101 ppm and greater.

TABLE 29-4. Summary of phytoplankton productivity rate per unit of chlorophyll a (mg carbon fixed/m^3/hr/mg chlorophyll a) associated with the three broad ranges of SWL concentration observed in the Everett area; for samples taken at the surface at temperatures equal to or greater than 10°C.

	SWL Concentration Range		
Statistic	0-50 ppm	51-100 ppm	Greater Than 101 ppm
Range	0.13 to 6.21	0.33 to 1.46	0.48 (only one value)
Mean	1.45	0.73	0.48
Median	0.96	0.52	0.48

DISCUSSION

It is shown that phytoplankton populations are essentially the same, qualitatively and quantitatively, at each of the stations examined in the Everett area. Phytoplankton productivity, also, varies little among stations throughout the study area except at Station I in Everett Harbor. At this site, the phytoplankton productivity rate commonly is quite low; hence the capacity of these waters to effectively support the lower organisms that serve as food for higher forms, such as salmon and oysters, is impaired. The conclusion drawn is that phytoplankton are continuously being swept throughout the study area by water currents and circulation, and, that once these cells are brought into contact with high concentrations of pulping wastes, they are physiologically injured and fail to function normally. This injury does not translate into alteration of the community structure because of the constant movement of phytoplankton into and out of the affected area.

The data presented in Figure 29-2 and Table 29-4 clearly show that the phytoplankton sustain significant injury at SWL concentrations greater than 50 ppm. Referring to Table 29-1, it is seen that average SWL concentration within the inner harbor is greater than 50 ppm. Consequently, this portion of the Everett study area is affected by water quality inimical to phytoplankton.

Abatement of this damage will require treatment or reduction of weak pulping and paper mill wastes discharged by the Weyerhaeuser and Scott mills. The relationship between productivity and SWL concentration (Figure 29-2) indicates that these pulping wastes are responsible for the observed damage and the location of the station (Station 1) where productivity is significantly reduced points to these mills as being the source of such wastes.

30. BACTERIAL QUALITY

The waters of Port Gardner, Everett Harbor, and the lower Snohomish River system are used for commercial and sport fishing, log rafting and sorting activities, towboat operations, pleasure boating, and shoreline recreation. Water contact incidental to these uses makes the bacterial quality of these waters important. Sources of bacterial pollution include the unchlorinated effluent from the City of Everett's waste-stabilization pond (see Figure 22-1 for pond location), and untreated wastes from boats and unsewered waterfront properties. To evaluate this pollution problem the Project conducted bacteriological studies in nearshore waters of the Everett area.

STUDIES

The Project conducted three representative bacteriological surveys in the Everett area, one each in March, April, and May 1965. On each survey, concentrations of total coliforms and fecal streptococci were determined for surface samples taken at each of 16 stations located in Port Gardner, Everett Harbor, and the lower Snohomish River (Figure 30-1). Associated surface water temperature and salinity also were measured at each station.

METHODS

Sample collection, handling, and bacterial analyses during the Everett area bacteriological studies were essentially the same as those described in Section 15.

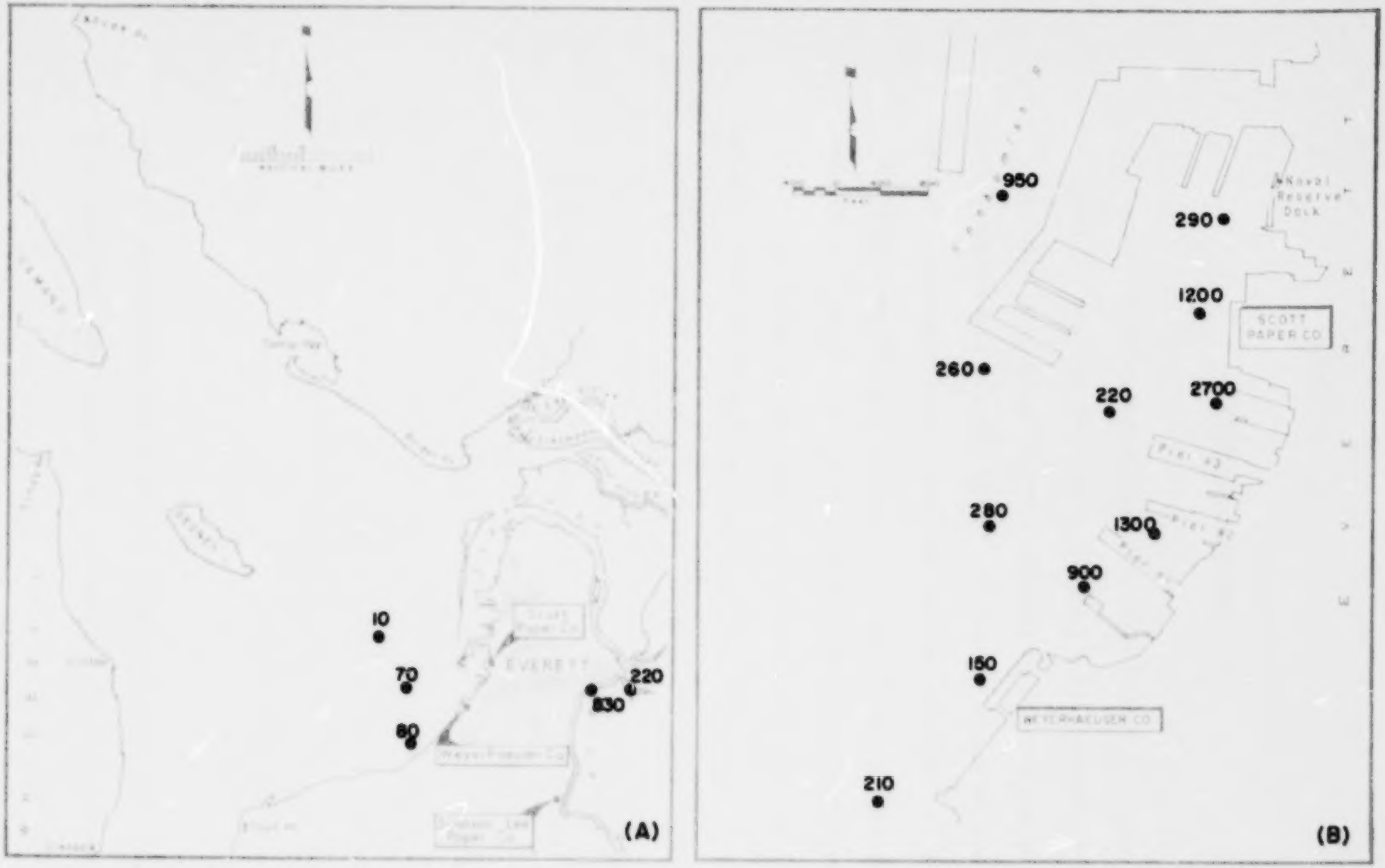

10
70
80
830
220
EVERETT
(A)
950
290
Naval Reserve Dock
1200
SCOTT PAPER CO.
260
220
2700
280
1300
900
150
WEYERHAEUSER CO.
210
(B)

FIGURE 30-1. Bacteriological sampling stations and three-cruise average concentrations of total coliforms in (A) Port Gardner and Snohomish River, and (B) Everett Harbor; data from Project studies, 1965.

RESULTS

Results of the Everett area bacteriological studies are shown in Figure 30-1 in terms of the three-survey average concentrations of total coliforms. Note that average bacterial counts in Port Gardner and the open waters of Everett Harbor were less than 300/100 ml, while counts in the lower Snohomish River and in certain dock-front areas of the Harbor were from about 800 to 2,700/100 ml. Fecal streptococci counts were variable but increased substantially when high counts of total coliforms were observed; this feature implies that the major source of bacterial contamination in the Everett study area is of human origin.

At each of the higher count stations in the lower River and Harbor area (Figure 30-1B) only one of the three coliforms readings averaged exceeded 600 organisms/100 ml, indicating an intermittent source. At the lower Snohomish River station (average coliform concentration of 950/100 ml, per Figure 30-1B) the high bacterial count was observed during the only ebb tide sampled; this suggests the City's waste stabilization pond, located upriver, as the most probable source. Within the Harbor, the intermittent high bacterial counts were observed in the active pier areas, most probably reflecting discharge of untreated wastes from cargo ships, sundry small boats, and unsewered dockfront properties. An additional possible source of intermittent contamination of the Harbor area is occasional storm overflow from the City's combined waste collection system.

DISCUSSION

Bacterial standards proposed by the Washington Pollution Control Commission for these waters require an average total coliforms concentration of less than 1,000/100 ml for water contact uses. Based on the Project's bacteriological studies, this criterion is essentially satisfied in most of the Everett study area. However, along the eastern dockfront of Everett Harbor, intermittent high bacterial counts raised the three-survey average coliforms concentrations to as much as 2,700/100 ml. Also, in the lower Snohomish River a high bacterial count on ebb tide resulted in only a marginally acceptable average coliforms concentration of 950/100 ml. These areas, then--the Everett Harbor dockfront, and, to a lesser extent, the lower Snohomish River--exhibit bacterial conditions which are potentially hazardous to public health.

Results of Project studies indicate that the most probable sources of bacterial contamination are the unchlorinated effluent from the City's waste stabilization pond on the Snohomish River, and untreated wastes from ships, small boats, and unsewered dockfront properties in Everett Harbor.

31. SUMMARY

The principal sources of wastes discharged to the Everett Harbor and Port Gardner are the Weyerhaeuser Company sulfite pulp mill and the Scott Paper Company pulp and paper mill located in Everett. Concentrated pulping wastes from these two operations are discharged through a deep-water outfall to Port Gardner, while large volumes of log-barking, pulp-washing, bleaching, and paper-making wastes are discharged to Everett Harbor immediately adjacent to the two mills. A portion of these latter wastes receive primary treatment prior to discharge.

Project studies have shown that damages resulting from these discharges are essentially of two types: (1) those associated with or caused by the discharge of large volumes of solids-bearing wastes to Everett Harbor adjacent to the Scott Paper Company and Weyerhaeuser Company mills, on occasion containing concentrations of toxic chemicals; and (2) those resulting from the toxic effects of the sulfite waste liquors when diluted and dispersed throughout the surface waters of Port Gardner, Possession Sound, Port Susan, and Saratoga Passage.

In Everett Harbor, discharges from Scott Paper Company and the Weyerhaeuser Company sulfite mill result in high waste concentrations, sludge deposits, and attendant water quality degradation. These conditions are incompatible with marine life and interfere with other legitimate water uses. These wastes have been shown to:

1. Cause injury or mortality to juvenile salmon migrating through Everett Harbor.
2. Cause extensive bottom sludge deposits which produce toxic concentrations of sulfides in the adjacent waters that are damaging to fish and bottom organisms and result in overall aesthetically unattractive conditions.
3. Suppress phytoplankton activity in the Everett Harbor area.

Abatement of these damages can be accomplished by providing for removal of all settleable solids from the wastes and removing the point of waste discharge from the confines of Everett Harbor.

The concentrations of sulfite waste liquor found in the surface waters throughout the study area present an even greater threat to marine communities indigenous to the area. As in the Bellingham-Samish Bay system, these wastes in dilute concentrations, 5-15 ppm SWL, have been shown to be damaging to larval forms of fish and shellfish found in the study area. English sole eggs and Pacific oyster larvae are two of the forms with which the Project has worked intensively but which represent a large group of marine organisms expected to be similarly affected. These include some 10 species of sole, 6 species of cod, 3 species of clams, and anchovy, herring, smelt, and crabs to mention a few of the more important.

Project studies have shown that such wastes:

1. Produce damages to developing English sole eggs found throughout the surface waters of Port Gardner and Everett Harbor. Extensive damage or mortality would be expected in and adjacent to Everett Harbor, with the

degree of damage decreasing at increasing distances from the waste source.

2. Produce extensive damage to oyster larvae. Similar damages would be expected to occur to other indigenous shellfish, as indicated by damages to the sessile intertidal organisms.

To prevent additional damages and provide minimum protection of these organisms during their most sensitive life stages, it is required that SWL concentrations in the surface 50 feet of depth not exceed 10 ppm beyond the initial waste dispersion zone. The initial waste dispersion zone is defined as that area of Everett Harbor and Port Gardner within a 1.5 mile radius of the southwestern tip of the peninsula bordering Everett Harbor.

Although the strong pulping wastes disposed by the Scott and Weyerhaeuser mills through the deep-water outfall produce relatively high SWL concentrations throughout the deep waters of the Everett area, the results of biological studies do not demonstrate that they presently cause any measurable damage to marine life inhabiting the deeper waters. Admittedly, these biological studies primarily treated marine forms that inhabit surface water. Review of presently available literature and considered judgment, however, have not produced any available evidence of damage or injury sustained by the marine life which populates the deep waters of the Everett area and which would be affected by the deep-water diffuser wastes. There remains some likelihood, though, that these wastes may, in diffusing upward, contribute to the surface SWL concentrations in the outer limits of the study area. It is not possible to determine to what extent this may occur.

Wastes from the Simpson Lee Company sulfate pulp mill are discharged into the Snohomish River some 10 miles upstream from its mouth. This mill is relatively small but does discharge significant quantities of settleable solids materials that contribute to the extensive bottom sludge deposits adjacent to the mouth of the Snohomish River.

The City of Everett's domestic wastes are treated in a waste stabilization pond and then discharged into the Snohomish River at a point 3.5 miles upstream from its mouth. Bacteriological studies in the River have shown that bacterial concentrations now approach, and at times exceed, those levels recommended by the Washington State Pollution Control Commission. Intermittently high bacterial counts were also noted in and adjacent to the Everett Harbor.

Part 5

PORT ANGELES STUDIES

32. INTRODUCTION

Fibreboard Paper Products Corporation's sulfite pulp and board mill and Rayonier Incorporated's sulfite pulp mill (Figure 32-1) are the waste sources of principal consideration in the Port Angeles area. Both mills discharge process wastes into the surface waters of Port Angeles Harbor.

Other major wastes sources in the study area are the Crown Zellerbach Corp. groundwood pulp and paper mill, the Pen-Ply plywood mill, the City of Port Angeles, and the U. S. Coast Guard Air Station. The locations of these sources and their points of discharge also are shown in Figure 32-1.

STUDY AREA

The Port Angeles study area includes Port Angeles Harbor and the near-shore waters of the Strait of Juan de Fuca from a point 2-1/2 miles west of the Elwha River mouth to the end of Dungeness Spit (Figure 32-2). Port Angeles is the only community within the area.

Port Angeles Harbor is partially enclosed by Ediz Hook. Its eastern boundary, where it opens to the Strait, is delimited by the arbitrary boundary shown in Figure 32-2. Depths in the southern half of the Harbor are less than 60 feet. In the northern half, depths to 192 feet occur.

The Strait of Juan de Fuca is one of the two channels--the Strait of Georgia being the other--connecting Puget Sound with the Pacific

Preceding page blank

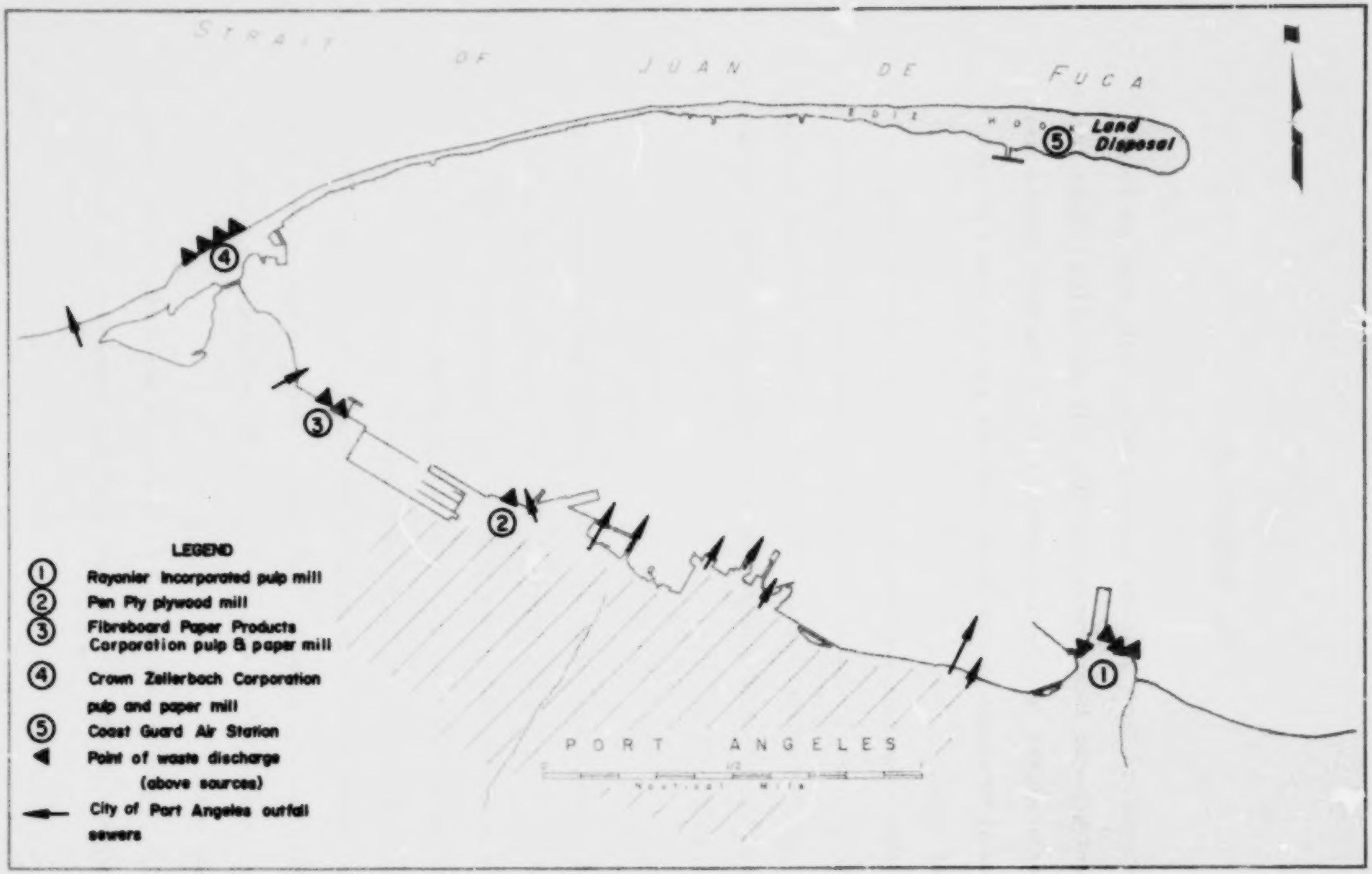

STRAIT OF JUAN DE FUCA
EDIZ HOOK
Land Disposal
⑤
④
③
②
①
PORT ANGELES
0
1/2
1
Nautical Mile
LEGEND
① Rayonier Incorporated pulp mill
② Pen Ply plywood mill
③ Fibreboard Paper Products Corporation pulp & paper mill
④ Crown Zellerbach Corporation pulp and paper mill
⑤ Coast Guard Air Station
◀ Point of waste discharge (above sources)
← City of Port Angeles outfall sewers

FIGURE 32-1. Location of waste sources in the Port Angeles area.

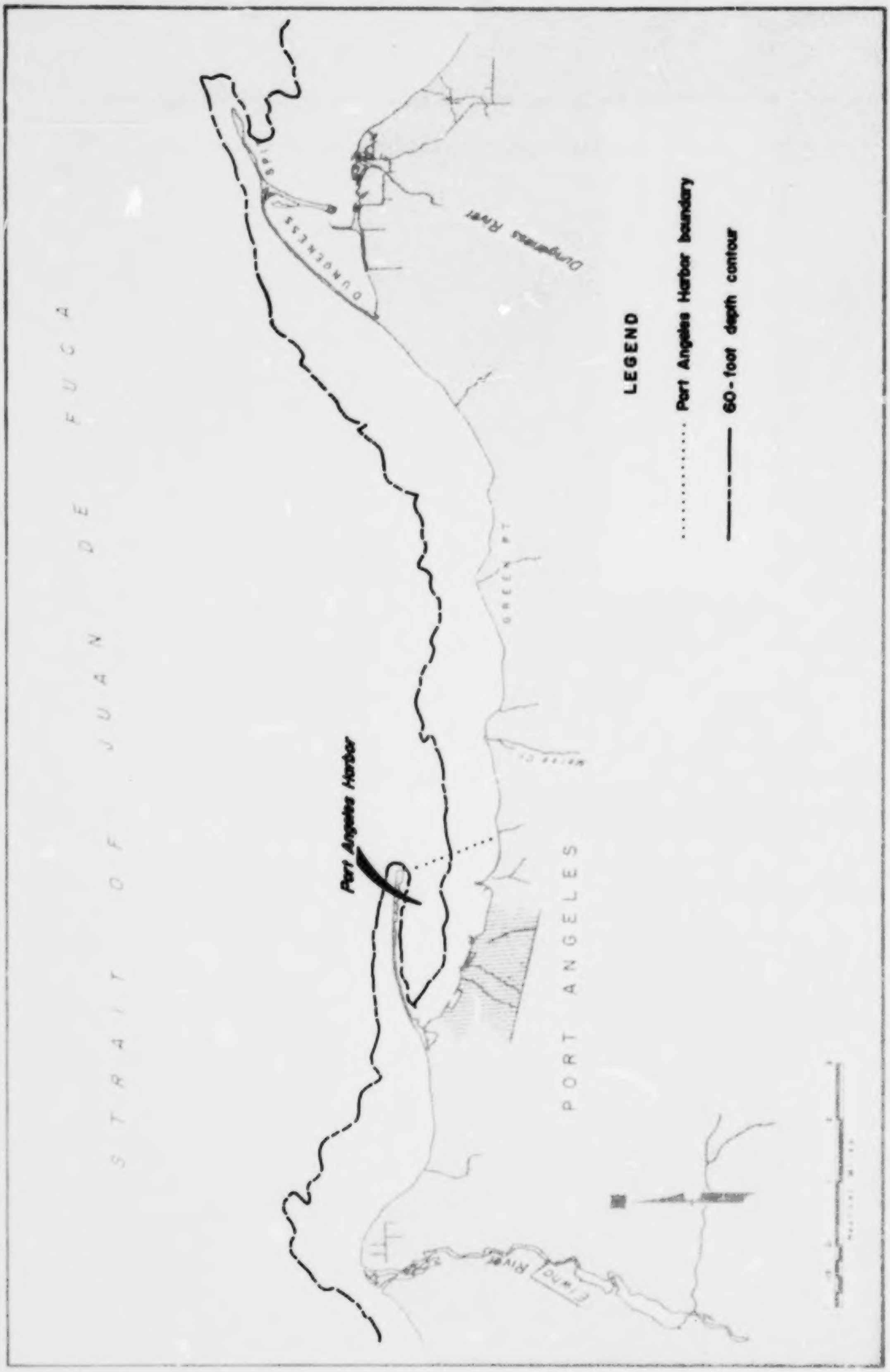

STRAIT OF JUAN DE FUCA
PORT ANGELES
Port Angeles Harbor
DUNGENESS SPIT
Dungeness River
GREEN PT
Elwha River
LEGEND
Port Angeles Harbor boundary
60-foot depth contour

FIGURE 32-2. Port Angeles study area.

Ocean. Accordingly, large volumes of tidal flows pass through the Strait and largely dominate water circulation in the study area.

33. WASTES

STUDIES

The principal waste sources of the Port Angeles area were the subject of in-plant waste surveys on the following dates:

Fibreboard Paper Products Corp.	July 16-19, 1963
	April 21-24, 1964
	October 27-30, 1964
Rayonier, Incorporated	September 16-19, 1963
	June 8-11, 1964
	October 5-7, 1964

During each survey, three 24-hour composite samples and additional grab samples were collected from each of several in-plant waste streams (see Figures 33-1 and 33-2). Project, State, and mill personnel acted jointly in collecting and analyzing these samples.

The State conducted an in-plant survey at the Crown Zellerbach Corp. during January 25-27, 1965 and collected a grab sample of total waste discharge from the Pen-Ply Plywood Mill on April 24, 1965. At the Crown Zellerbach mill, three 24-hour composite samples and additional grab samples were collected from each of six in-plant waste streams.

Waste discharges from the City of Port Angeles sewer system were not sampled. Information on population served, total waste discharge, and location of outfall sewers was obtained from the City's consultant; Cornell, Howland, Hayes, and Merryfield. Information on the Coast Guard Air Station waste treatment facilities was obtained from an engineering report by the 13th Coast Guard District.

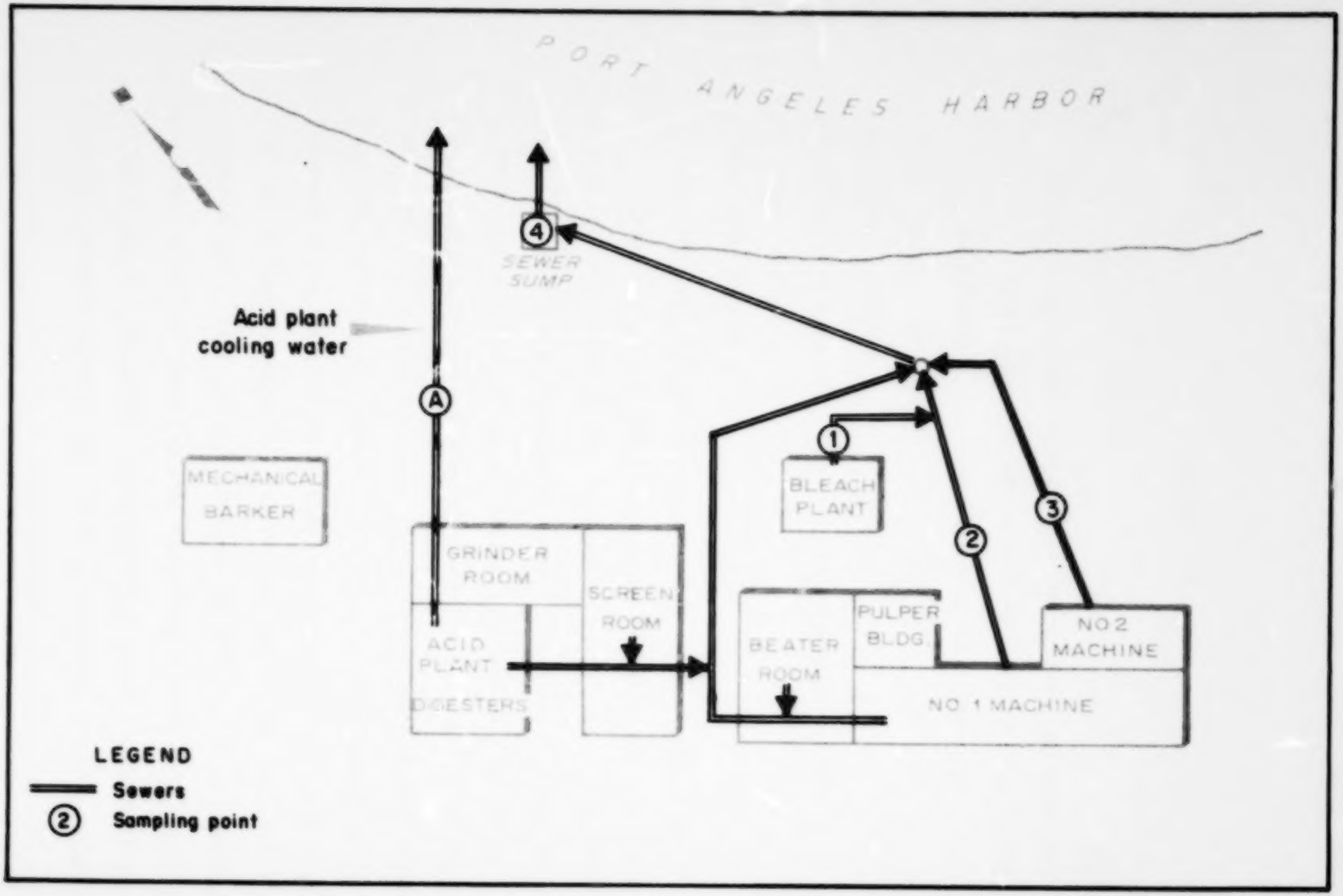

PORT ANGELES HARBOR
4
SEWER SUMP
Acid plant cooling water
A
MECHANICAL BARKER
GRINDER ROOM
ACID PLANT
DIGESTERS
SCREEN ROOM
1
BLEACH PLANT
BEATER ROOM
PULPER BLDG.
2
3
NO 2 MACHINE
NO 1 MACHINE
LEGEND
Sewers
2
Sampling point

FIGURE 33-1. Schematic diagram of mill layout, sewer system, and sampling points; Fibreboard Paper Products Corporation, Port Angeles, Washington.

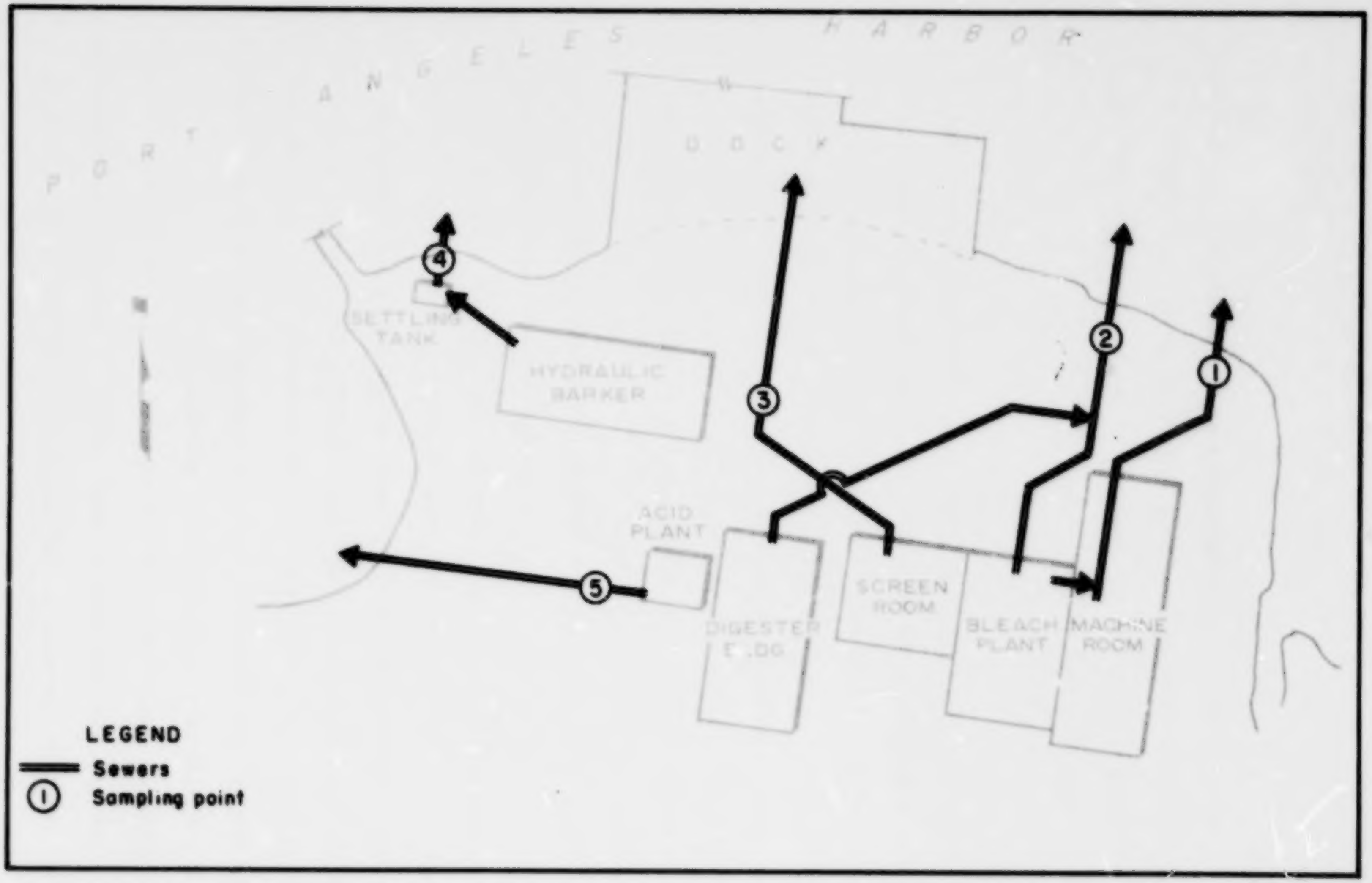

PORT ANGELES HARBOR
DOCK
SETTLING TANK
HYDRAULIC BARKER
ACID PLANT
DIGESTER BLDG
SCREEN ROOM
BLEACH PLANT
MACHINE ROOM
①
②
③
④
⑤
LEGEND
Sewers
① Sampling point

FIGURE 33-2. Schematic diagram of mill layout, sewer system, and sampling points. Rayonier Incorporated, Port Angeles, Washington.

METHODS

Survey procedures, and sampling and analytical methods employed in the Fibreboard, Rayonier, and Crown Zellerbach surveys were similar to those described in Section 6. Analyses of the Pen-Ply sample were the same as those described in Section 6.

RESULTS

Fibreboard Paper Products Corporation. This mill, located near the west end of Port Angeles Harbor (see Figure 32-1), produces about 60 tons per day of bleached, ammonia-base sulfite pulp, about 40 tons per day of stone groundwood pulp, and variable quantities of re-pulped waste paper. Re-pulped waste paper and virgin pulp are used to produce about 100 tons per day of board stock for packaging and wallboard. Excess virgin pulp is dried for shipment to other company-owned mills. Mechanical log barking is employed.

Figure 33-1 is a schematic diagram of the mill layout, sewer system, and sampling points. The principal in-plant sewers (solid lines) combine and discharge through a single sewer into near-surface waters of the Harbor. Composite samples from sampling point #4 were used to measure the mill's total waste load. The sewer designated by the dashed-line normally carries only acid plant cooling water, but occasionally, it also carries some overflow of fiber from the groundwood mill. Although this sewer was not the subject of composite sampling, a series of settleable solids samples were collected from sampling point A.

Averaged results of the mill's total waste load, as obtained in the three surveys, are tabulated in Table 33-1. The pounds-per-ton-production values shown are computed on the basis of the combined production of the bleached sulfite pulp, groundwood pulp, and board; hence they are not comparable with similar load values from the other mills surveyed.

TABLE 33-1. Average daily waste load discharged by the Fibreboard Paper Products Corporation, Port Angeles, Washington

Analyses	#/Ton of Production	Tons/Day
BOD_5	228	22
COD	983	94
SWL [1]	9,150	864
Total Sulfur	53	5.1
Total Solids	794	76
Volatile	686	65
Suspended Solids	46.2	4.4
Volatile	42.9	4.1
Supernatant Suspended Solids	10.3	1.0
Ave. Tons Production/Day [2]	191	
Ave. % Volatile Susp. Solids Loss	2.1	
Ave. Waste Volume, mgd	4.2	

[1] Weight of a 10% solids solution, per ton or per day as indicated.

[2] Combined production of board, and groundwood and bleached sulfite pulp (air dried).

Rayonier, Incorporated. This mill (see Figure 32-1 for location) produces both dissolving and paper grade pulp by the calcium-base sulfite process. Pulp is bleached, dried, and shipped to market. No paper products are produced. Pulp production, a mixture of both dissolving and paper grades, during the three in-plant surveys averaged 467 tons per day.

A schematic diagram of the mill layout, sewer system, and sampling points is shown in Figure 33-2. Note that hydraulic barker wastes are passed through a settling tank prior to discharge. Although settling time is brief, some solids are removed. These are diverted to a hog fuel pile and burned. Settled barker wastes and all other mill wastes are discharged into the near-surface waters of the Harbor through the five outfall sewers shown.

Averaged results of Rayonier mill's total waste load, as obtained in the three surveys, are tabulated in Table 33-2.

Crown Zellerbach Corp. This mill produces about 95 tons per day of refiner groundwood pulp, about 305 tons per day of stone groundwood pulp, and about 480 tons per day of newsprint and telephone directory paper. All pulp production is bleached. Both mechanical and hydraulic barking are employed.

Hydraulic barker wastes discharge into a lagoon on mill property where settleable solids are removed. Sanitary wastes flow to septic tanks from which effluents discharge into the Strait of Juan de Fuca. All pulp and paper mill process wastes presently are discharged through four sewers into the near-surface waters of the Strait (see Figure 32-1). Previously, however, some high solids wastes were disposed into Port Angeles Harbor where they produced a sludge deposit (see Section 34).

TABLE 33-2. Average daily waste load discharged by Rayonier, Inc., Port Angeles, Washington.

Analyses	#/Ton of Production	Tons/Day
BOD_5	1,031	235
COD	4,638	1,057
SWL*	41,360	9,430
Total Sulfur	302	69.5
Total Solids	5,110	1,157
Volatile	3,202	727
Suspended Solids	70.5	16.7
Volatile	63.9	15.1
Supernatant Suspended Solids	20.5	4.9
Ave. Tons Production/Day (air dried)	467	
Ave. % Volatile Susp. Solids Loss	3.2	
Ave. Waste Volume, mgd	35.66	

* Weight of a 10% solids solution, per ton or per day as indicated.

Averaged survey results--the mill's total daily waste load--are tabulated in Table 33-3.

The pulping processes employed by the Crown Zellerbach mill differ greatly from the sulfite and sulfate (kraft) processes previously described. Both the refiner groundwood and stone groundwood processes are mechanical defibering operations. Steam is used to soften the wood chips, but no chemical digestion is employed. Consequently, dissolved chemicals, lignins, and wood sugars -- materials which impart BOD_5, COD, SWL, and total solids to a waste -- are present in low concentrations in the mill's pulping wastes. The bleaching operation, however, does generate some quantity of these waste materials. Note, then, that the BOD_5, COD, apparent SWL, total sulfur, total solids, and total volatile solids loads (Table 33-3) discharged by the Crown Zellerbach mill are comparatively much smaller than respective loads from the sulfite mills surveyed. On the other hand, the suspended solids loss from the Crown Zellerbach mill is very high (Table 33-3), compared to the other mills surveyed. This results from higher fiber losses of groundwood pulping as against chemical pulping.

Pen-Ply Mill. This plywood manufacturer discharges glue wastes into Port Angeles Harbor (see Figure 32-1). Estimated waste flow is 5 gpm.

Sampling results, as interpolated for a 24-hour, 5 gpm flow, are given in Table 33-3. The indicated apparent-SWL load derives from phenolic compounds of the glue wastes.

Port Angeles Sewage. The City of Port Angeles discharges untreated domestic wastes from a population of 15,300 into Port Angeles Harbor through nine outfall sewers and into the Strait of Juan de Fuca through one outfall sewer (see Figure 32-1). The consulting engineering firm of Cornell, Howland, Hayes, and Merryfield has prepared a preliminary report on interceptor and primary treatment facilities needed to abate these untreated discharges. The next actions will be for the City to hold a bond election and have their consultant prepare construction plans and specifications.

TABLE 33-3. Daily waste loads discharged by other major waste sources in the Port Angeles area.

	Tons/Day		
Analyses	Crown Zellerbach Corporation	Pen-Ply Mill	Port Angeles Sewage [1]
BOD_5	12.1	0.2	1.9
COD	52.1	- -	- -
Apparent SWL [2]	393	6.5	- -
Total Sulfur	1.1	- -	- -
Total Solids	46.7	0.2	7.4
Volatile	36.7	< 0.1	3.9
Suspended Solids	35.9	< 0.1	1.8
Volatile	34.3	< 0.1	1.2
Supernatant Susp. Solids	6.5	- -	- -
Waste Volume, mgd	9.7	0.1	2.2 [3]

[1] Computed waste load based on 2.2 mgd flow and sewage characteristics of 210 ppm BOD_5, 800 ppm total solids, 420 ppm volatile total solids, 200 ppm suspended solids, 135 ppm volatile suspended solids, and 130 ppm supernatant suspended solids.

[2] From non-sulfite-pulping constituents which give an apparent-SWL indication in the Pearl-Benson test -- equivalent to tons of a 10% solids solution per day.

[3] Dry weather discharge. Wet weather discharge is 6.8 mgd.

The aggregate waste load presently disposed by the City is given in Table 33-3. Values shown were computed from the City's average daily discharge of 2.2 mgd and estimated concentrations of BOD_5, total solids, and suspended solids.

Coast Guard Air Station. This air station, including a Naval Reserve barracks, is located at the end of Ediz Hook (see Figure 32-1). Prior to May 1966, it discharged untreated domestic wastes into Port Angeles Harbor. Presently, its wastes are treated in four septic tanks and disposed by drainfields on the Hook. These facilities are designed to handle wastes from over 225 persons, and they are considered adequate by the Washington State Health Department.

DISCUSSION

Figure 33-3 compares the combined daily waste load from the Rayonier and Fibreboard mills with the combined load from the other major waste sources in the study area; viz., the Crown Zellerbach mill, the Pen-Ply mill, and the City of Port Angeles. For the waste categories of SWL (and apparent SWL), COD, BOD_5, and total solids, the Rayonier and Fibreboard mills are, very clearly, the principal sources. Furthermore, of these two mills, Rayonier is the larger source; it contributes about 92% of their combined load (compare values from Tables 33-1 and 33-2). Accordingly, if discharges of these waste properties are to be reduced to protect water quality and marine life of the Harbor, treatment of Rayonier and Fibreboard wastes, particularly their sulfite pulping wastes, will be necessary.

For the category of suspended solids (Figure 33-3), combined discharges from the other waste sources surpass those from the Rayonier and

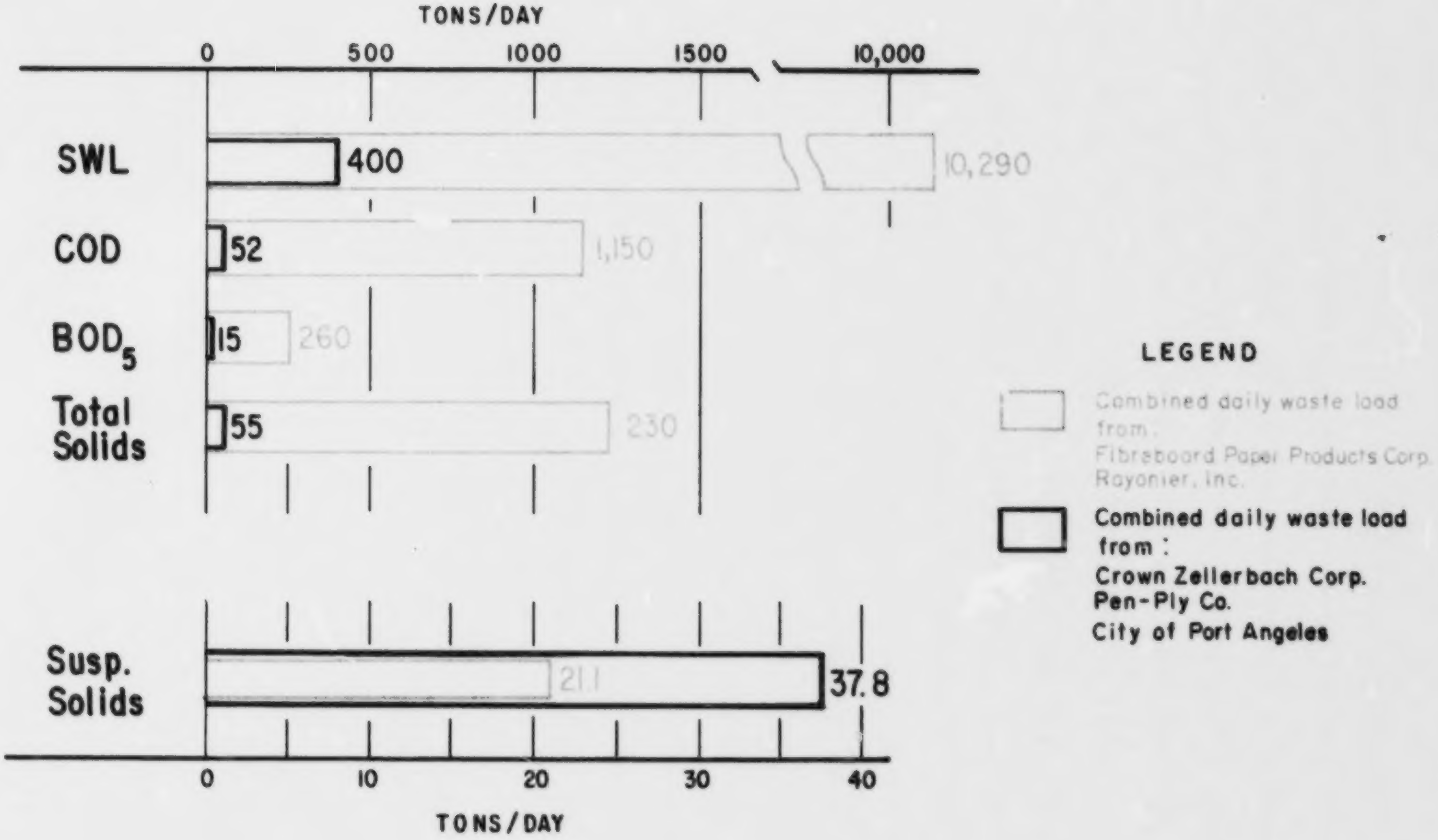


FIGURE 33-3. Delineation of the total daily waste load discharged into Port Angeles Harbor and the Strait of Juan de Fuca.

Fibreboard mills. This obtains from the exceptionally high suspended solids loss in Crown Zellerbach's groundwood pulping and paper operation--some 35.9 tons per day (Table 33-3). Settling tests (Imhoff cone) indicate that suspended solids losses can be reduced to 6.5 tons per day at the Crown Zellerbach mill, to 4.9 tons per day at the Rayonier mill, and to 1.0 tons per day at the Fibreboard mill. In total, a reduction to 12.4 tons per day from the 57.0 tons per day presently discharged. Adequately sized and designed sedimentation facilities would effect these reductions.

The discharge of raw sewage by the City of Port Angeles is a sanitary malpractice capable of causing serious bacterial pollution (see Section 38) and endangering health. The Washington Pollution Control Commission has a long-standing policy requiring primary treatment (sedimentation) and disinfection of any domestic wastes discharged into surface waters. The City has been notified of the policy and has started action to comply.

34. WASTE DISTRIBUTION AND WATER QUALITY

STUDIES

The Project conducted oceanographic and related studies in the Port Angeles area to (1) describe distribution of wastes from the Crown Zellerbach, Fibreboard, and Rayonier mills, and (2) determine the effects of these wastes on water quality and bottom sediments.

Others have conducted independent studies of pollution in the Port Angeles area as follows:

Washington Pollution Control Commission: Peterson and Gibbs (1957) investigated municipal and pulp mill pollution in a study which included float studies to determine water circulation patterns, and water sampling surveys to measure temperature, salinity, DO, SWL, and bacteria; Pine and Clemetson (1961) used skin divers to make visual observations of the marine biota and bottom sediments near Rayonier and Fibreboard mills; water temperature, concentrations of salinity, DO, SWL, and sulfides, and volatile solids content of bottom grab samples were measured by Ott, Livingston, and Mills (1961).

Rayonier, Incorporated: Charnell (1958) summarized the results of extensive field surveys of pulp mill wastes in Port Angeles Harbor, including float studies, determinations of water temperature, salinity, DO, SWL, and pH, and observations of the nearshore marine biota; Stein, Denison, and Isaac (1963) discussed flood tide distributions of salinity, DO, SWL, pH, and water transparency in Port Angeles Harbor, skin diver reconnaissance of sludge deposits adjacent to Rayonier mill, and observations of marine biota.

The results of these studies were reviewed and considered along with Project data.

Circulation Studies. Four float studies were conducted by the Project, one each in September, October, and November, 1962, and September 1963. Each study consisted of tracking the movement of 8 to 10 crossed-vane current drogues released at various locations and depths in Port Angeles Harbor. Both flood and ebb tide conditions were tested.

The Project also conducted an exploratory dye study near the Fibreboard outfalls in July 1962. Equipment failure limited the scope of this study to visual observations of dye movement at the surface.

At the Project's request, the U. S. Coast and Geodetic Survey occupied a current-monitoring station in the Harbor (Figure 34-1A) during its 1964-65 current study of northern Puget Sound. Currents were observed at the 15-, 87-, and 145-foot depths for a 100-hour period, July 14-18, 1964. Data for this station and for several other stations in the adjacent Strait of Juan de Fuca were provided the Project as graphs of current speed and direction.

In addition to actual measurements of currents, net water circulation was inferred from observed distributions of wastes, water quality, and water density.

Waste Distribution and Water Quality Studies. The Project conducted 14 oceanographic cruises in the Port Angeles area at approximately monthly intervals between September 1962 and January 1964. Principal sampling stations were located as shown on Figure 34-1A. The sampling station located in the Strait of Juan de Fuca about one mile

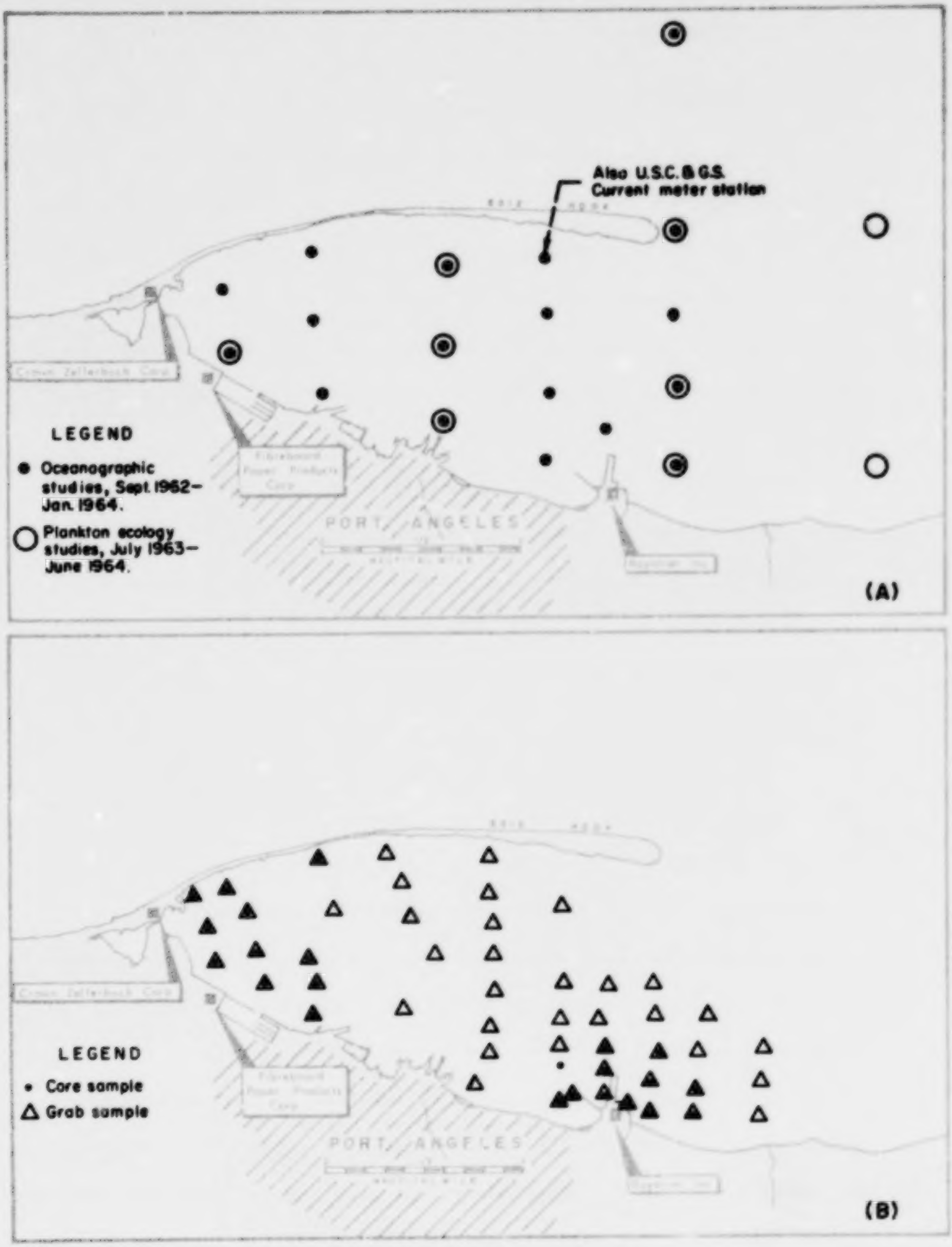

Also U.S.C.&G.S.
Current meter station
EDIZ HOOK
Crown Zellerbach Corp.
Fibreboard Paper Products Corp.
PORT ANGELES
NAUTICAL MILE
Rayonier Inc.
LEGEND
● Oceanographic studies, Sept. 1962–Jan. 1964.
○ Plankton ecology studies, July 1963–June 1964.
(A)
LEGEND
• Core sample
△ Grab sample
(B)

FIGURE 34-1. (A) Water sampling stations occupied in the Port Angeles area during the oceanographic and plankton ecology studies, and (B) bottom sediment sampling stations occupied in Port Angeles Harbor on September 30, 1964.

north of Ediz Hook was selected as a "control" station, representative of Strait waters unaffected by local pulp mill pollution. At each station, samples were taken from the surface and the 2-, 5-, 10-, 20-, 30-, 50-, and 70-meter depths, total depth permitting. Water properties measured were temperature, salinity, DO, SWL, and pH. Secchi-disc measurements and weather conditions also were recorded for each station. One cruise, on August 30, 1963, was conducted during a period when the Rayonier mill was closed by a labor strike.

Water quality data in the Port Angeles area also was collected during each of several biological studies conducted by the Project. In particular, water quality data comparable to that collected during the oceanographic studies were obtained during nine plankton ecology cruises conducted between July 1963 and June 1964. Stations sampled are shown also on Figure 34-1A.

Bottom Deposit Studies. On September 30, 1964, the Project collected 22 core samples and 50 grab samples from the floor of Port Angeles Harbor (Figure 34-1B). This study was conducted to (1) determine composition of bottom sediments, (2) describe areas of sludge accumulation, and (3) describe the benthos. The core samples, taken with a gravity coring apparatus, were examined in the field for sediment texture, color, odor, and sludge layer thickness. Grab samples of the surface sediments were taken by van Veen dredge and were examined in the field for odor, color, and inclusion of wood fibers and fragments and other constituents. Portions of the grab samples also were analyzed in the laboratory for volatile solids content and for included benthos (see Section 36).

METHODS

Field and analytical methods used in the Port Angeles area waste distribution and water quality studies were similar to those described in Section 7 and in the references cited.

RESULTS

Tidal Currents. Tidal current predictions are listed (U.S.C.&G.S., 1966) for nearby points in the Strait of Juan de Fuca, but not for points within Port Angeles Harbor. Currents in Port Angeles Harbor consist of a dominant eddy motion, generated by currents in the adjacent Strait of Juan de Fuca, superposed upon weak tidal filling and emptying currents. The eddy develops nearshore between Ediz Hook and Dungeness Spit and, in general, tranports water alongshore in the direction opposite to main currents in the Strait (Figure 34-2). The western boundary of the eddy is usually located just inside the Harbor entrance; thus Rayonier wastes most often are dispersed into the eddy fringe rather than into the "closed" circulation of Port Angeles Harbor.

Due to interaction and resonance effects in Puget Sound basin, flood and ebb currents in the Strait of Juan de Fuca are not necessarily in phase with their respective counterparts of rising and falling tide levels at Port Angeles; thus, the Harbor may either fill or empty coincident with flood or ebb current in the Strait. Generalized surface current patterns in Port Angeles Harbor for both rising (filling) and falling (emptying) tide levels are shown in Figure 34-3 for flood current in the Strait and in Figure 34-4 for ebb current in the Strait. Near-surface currents in the Strait of Juan de Fuca are generally less than 2 knots in magnitude and have a definite ebb-direction predominance

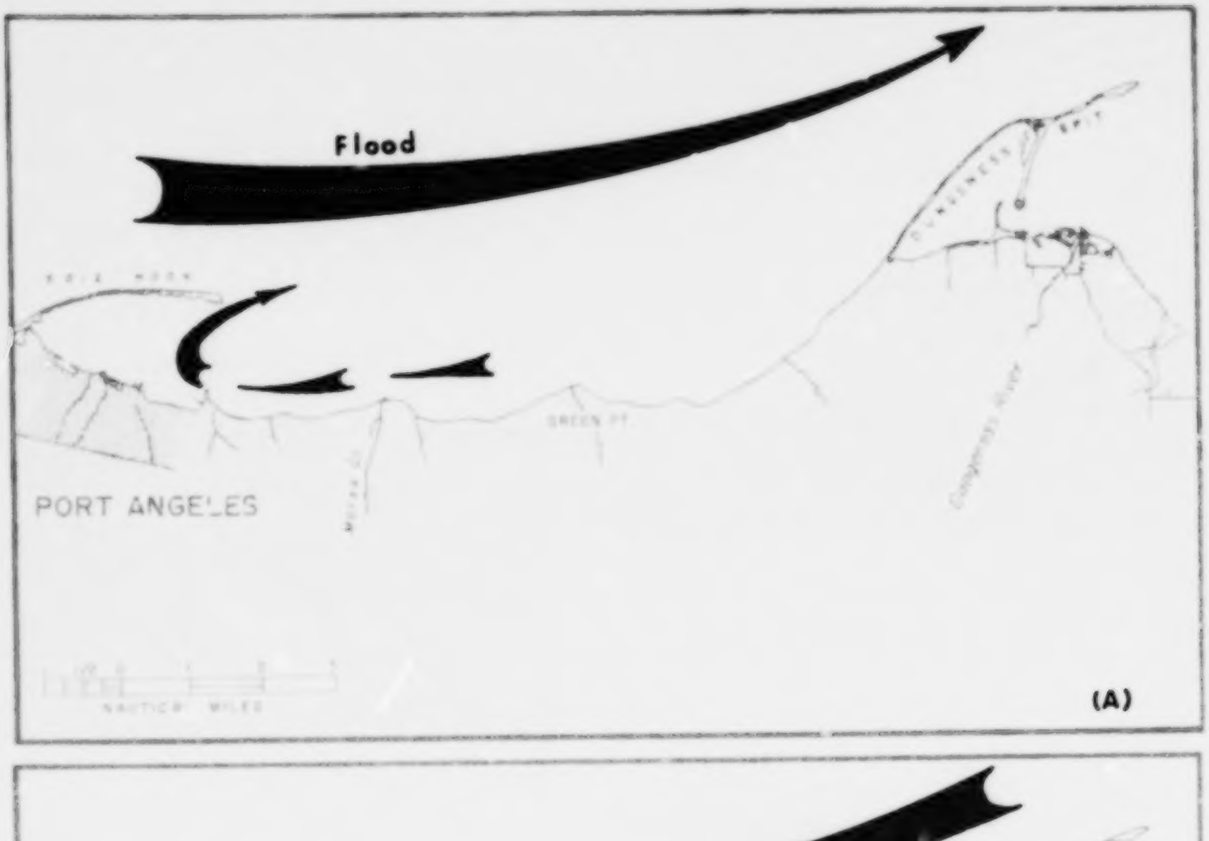

Flood
EDIZ HOOK
DUNGENESS SPIT
GREEN PT.
Morse Cr.
Dungeness River
PORT ANGELES
NAUTICAL MILES
(A)
Ebb
EDIZ HOOK
DUNGENESS SPIT
GREEN PT.
Morse Cr.
Dungeness River
PORT ANGELES
NAUTICAL MILES
(B)

FIGURE 34-2. Eddy circulation patterns alongshore between Ediz Hook and Dungeness Spit during (A) flood and (B) ebb currents in the Strait of Juan de Fuca.

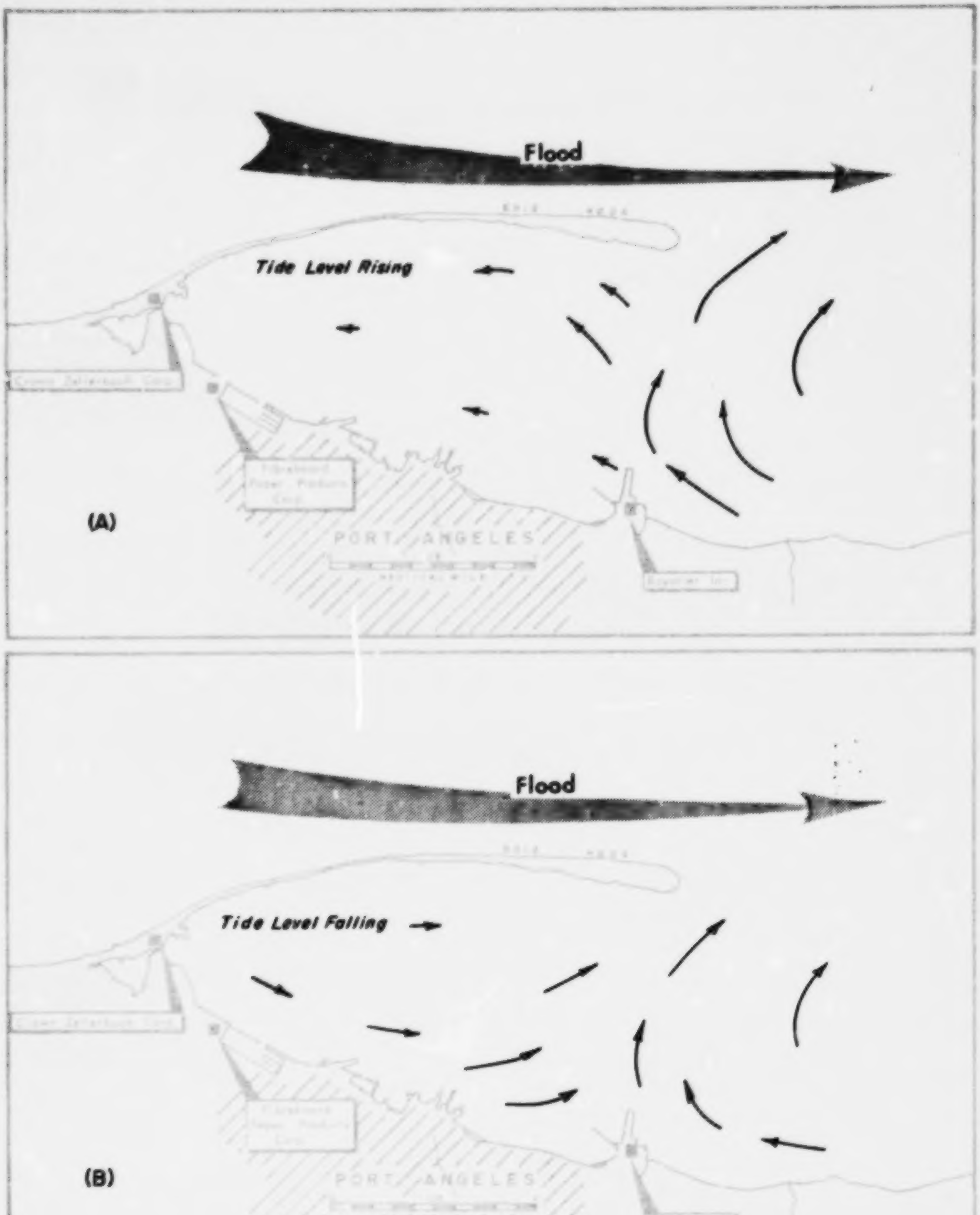

Flood
EDIZ HOOK
Tide Level Rising
Crown Zellerbach Corp.
Fibreboard Paper Products Corp.
(A)
PORT ANGELES
NAUTICAL MILE
Rayonier Inc.
Flood
EDIZ HOOK
Tide Level Falling
Crown Zellerbach Corp.
Fibreboard Paper Products Corp.
(B)
PORT ANGELES
NAUTICAL MILE
Rayonier Inc.

FIGURE 34-3. Patterns of surface circulation during flood current in the Strait and under conditions of (A) rising tide level and (B) falling tide level within the Harbor (after Charnell, 1958).

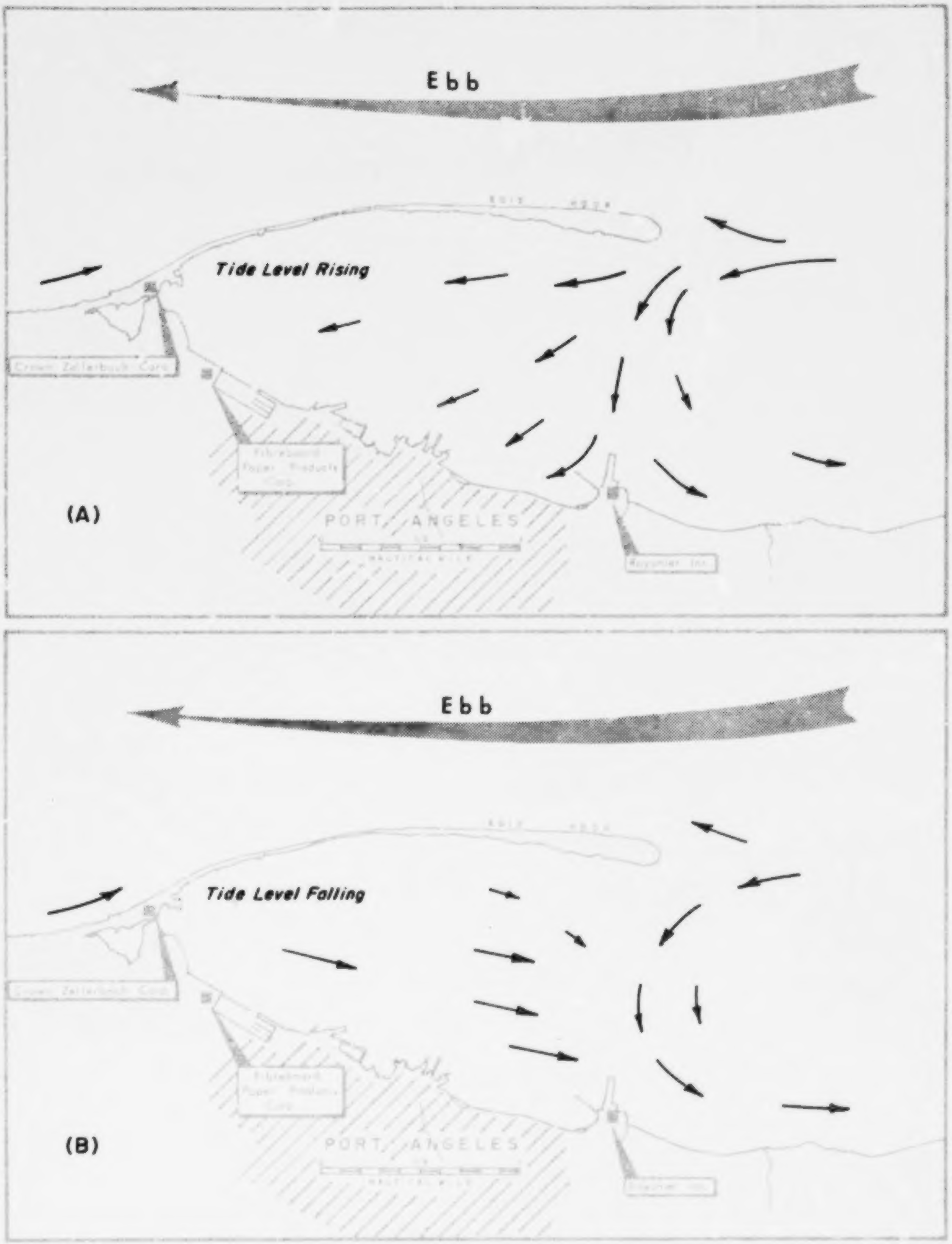

Ebb
EDIZ HOOK
Tide Level Rising
Crown Zellerbach Corp.
Fibreboard Paper Products Corp.
(A)
PORT ANGELES
NAUTICAL MILE
Rayonier Inc.
Ebb
EDIZ HOOK
Tide Level Falling
Crown Zellerbach Corp.
Fibreboard Paper Products Corp.
(B)
PORT ANGELES
NAUTICAL MILE
Rayonier Inc.

FIGURE 34-4. Patterns of surface circulation during ebb current in the Strait and under conditions of (A) rising tide level, and (B) falling tide level, within the Harbor (after Charnell, 1958).

due to seaward movement of freshwater inflow to Puget Sound basin. Within Port Angeles Harbor surface currents are generally less than 0.5 knot, unless wind-aided, with long periods of essentially slack motion in the northern and western portions. Flood tide motion occurs mostly in the northern portion of the Harbor, while ebb movement is most prominent in the southern portion. This motion results in a net anticlockwise circulation which tends to disperse Fibreboard wastes eastward through the southern portion of the Harbor.

Surface Layer. Freshwater from land drainage in Puget Sound basin moves seaward in the near-surface waters of the Strait of Juan de Fuca. This results in a generally stable density stratification of waters throughout the Port Angeles study area. Freshwater sources within the Harbor consist of municipal and industrial waste discharges and several small seasonal creeks along the southern shore. These local inflows add to near-surface density stability in Port Angeles Harbor as well as provide for a net outflow of surface waters, particularly in the southern portion. There are no local large freshwater sources; thus, the vertical density gradient is much more gradual than in the Bellingham and Everett areas, and a waste-confining surface layer does not usually develop. The stratification is sufficient, however, to inhibit downward mixing of surface-discharged wastes, with the result that highest waste concentrations are found mostly at the surface.

Net Circulation. Net circulation of surface waters in the Port Angeles area is characterized by:

1. A net anticlockwise circulation within Port Angeles Harbor, due to predominance of northside flood and southside ebb motion.

2. A net ebb-direction transport in the Strait of Juan de Fuca of about 2 miles per day, due to seaward movement of freshwater land drainage (Herlinveaux and Tully, 1961).
3. A net eastward drift alongshore between Port Angeles Harbor and Dungeness Spit, due to eddy movement associated with net ebb-direction transport in the Strait.

The main effects of net circulation on waste distribution in the Port Angeles area are the general restriction of wastes to the southern portion of the Harbor, the movement of some wastes eastward alongshore toward Dungeness Spit, and their eventual transport seaward once dispersed into the Strait.

Vertical Waste Distribution. Vertical distributions of average, maximum, and minimum SWL concentrations are shown in Figure 34-5 for four representative stations in Port Angeles Harbor. Vertical distribution of average SWL along a north-south transect within the Harbor entrance is shown in Figure 34-6A. These patterns of vertical waste distribution illustrate:

1. Waste concentration generally decreases with depth throughout the Port; this is most pronounced nearest the waste sources, becoming less evident with distance from the sources.
2. A well-defined, waste-restricting surface layer is not present; except for locations very near the waste sources, the gradient of average waste concentration with depth is fairly uniform from surface to bottom.
3. At least some waste concentration is present at all depths within the Port; samples taken at the "control" station in

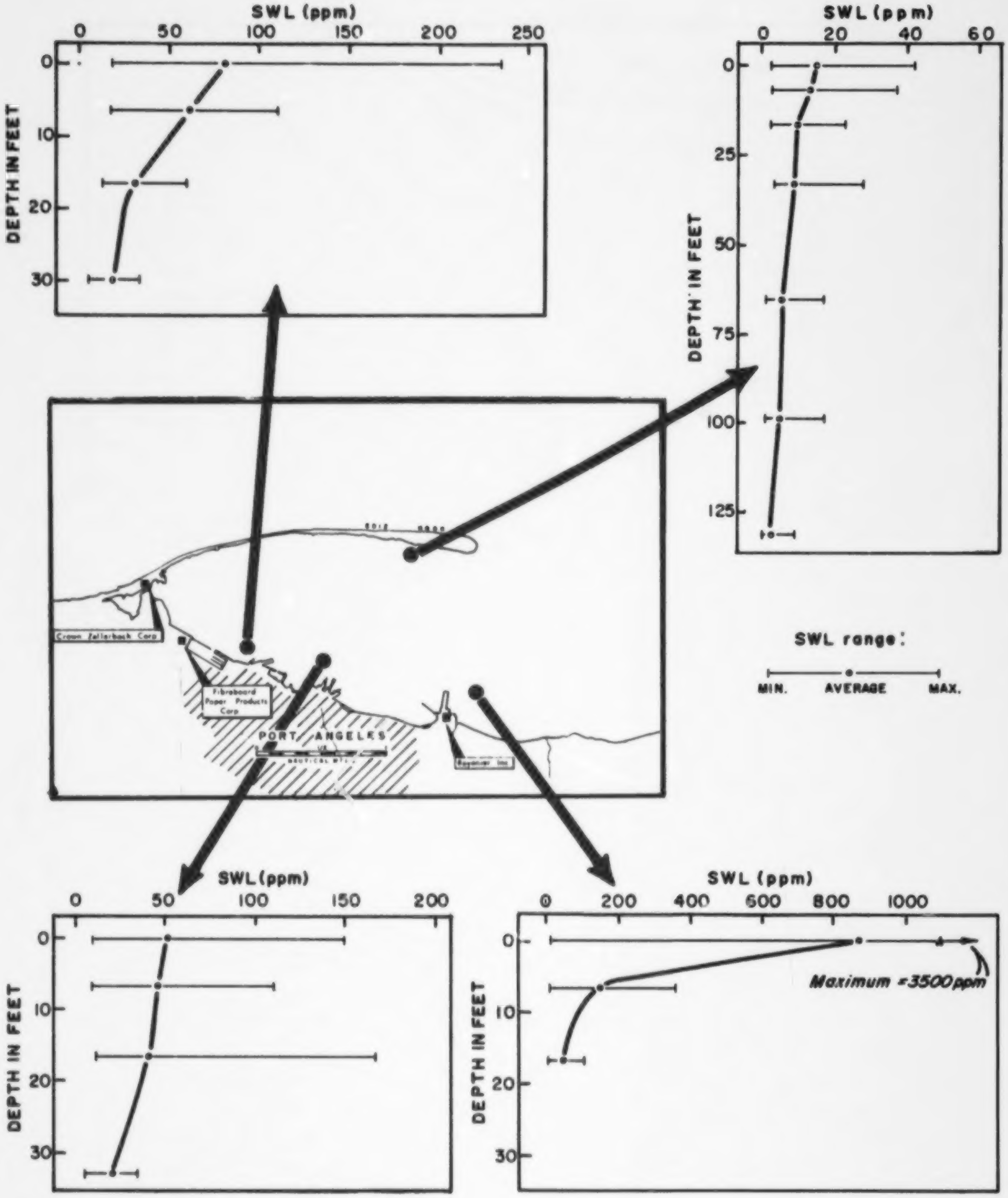


FIGURE 34-5. Vertical distribution of average, maximum, and minimum SWL concentrations at four stations in Port Angeles Harbor; data from oceanographic studies, September 1962 to January 1964.

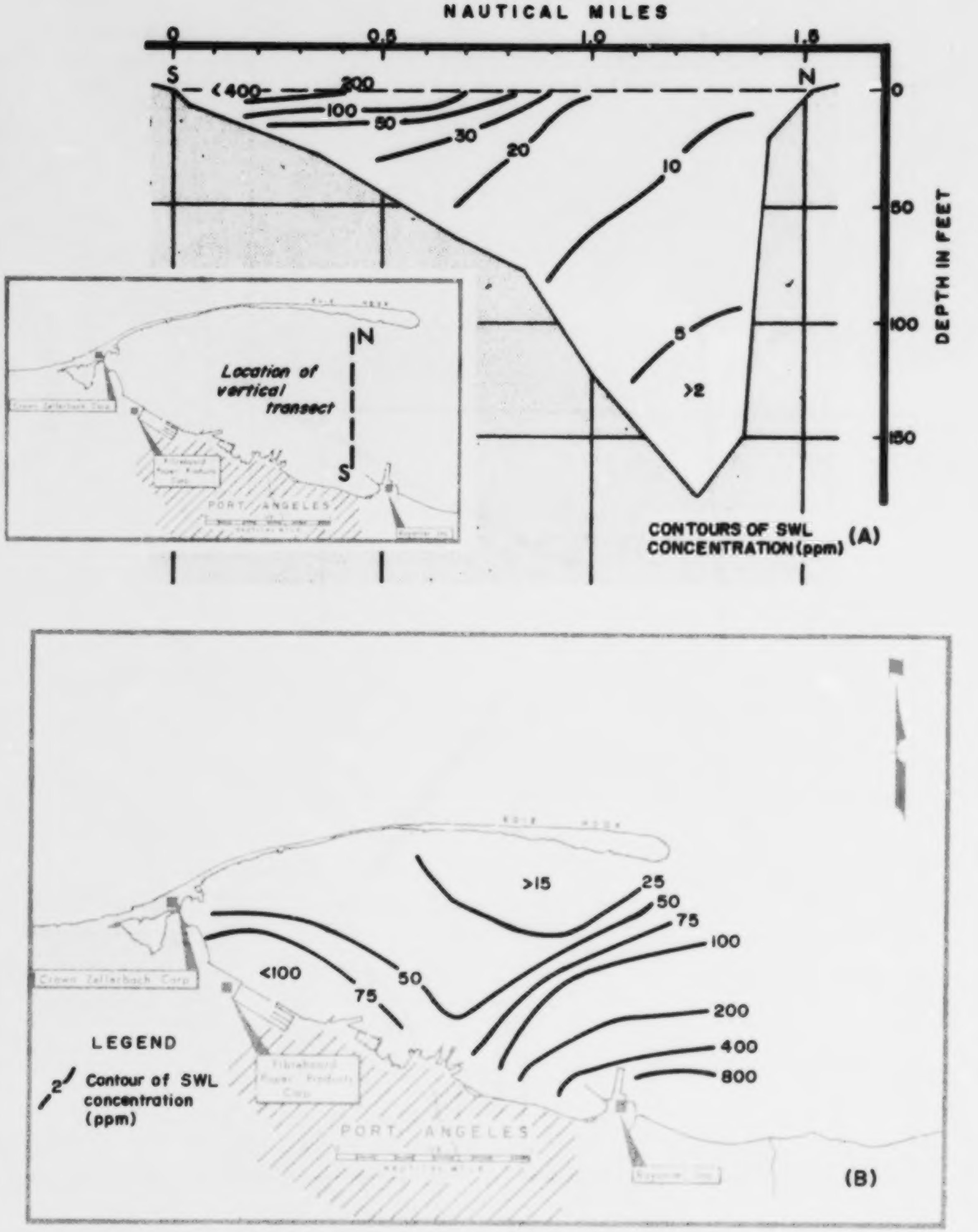


FIGURE 34-6. Distribution of average SWL concentrations (A) along a north-south vertical transect within the Harbor entrance; and (B) at the surface in the Harbor; data from oceanographic studies, September 1962 to January 1964.

the Strait during each cruise and in the Harbor during a pulp mill closure showed that background SWL (PBI) values are less than two ppm at the surface and less than one ppm at depths greater than 50 feet.

In addition, the vertical transect of waste distribution (Figure 34-6A) shows the tendency for confinement of the bulk of the wastes to the southern portion of the Harbor.

Horizontal Waste Distribution. Horizontal distribution of pulp mill wastes in the Port Angeles area is shown by the patterns of average surface SWL within the Harbor (Figure 34-6B) and between the Harbor and Dungeness Spit (Figure 34-7B). These distributions show the general confinement of the bulk of the wastes to the southern portion of the Harbor, as well as eventual movement of some wastes eastward toward Dungeness Spit; both features are consistent with water circulation patterns previously described. Maximum observed surface SWL concentrations within the Harbor (Figure 34-7A) and between the Harbor and Dungeness Spit (Figure 34-7B) are distributed in essentially the same patterns as average SWL. These maximum SWL values--from about two to more than ten times as great as corresponding average values, depending on location--illustrate the extent to which short-term water circulation affects waste movement in the Port Angeles area; for instance, the high maximum values near Ediz Hook (Figure 34-7A) reflect the intermittent northward circulation of Rayonier mill wastes through eddy-siphoning action by flood current in the Strait (see Figures 34-2 and 34-3).

Flushing of Wastes During Mill Closure. No wastes were discharged from Rayonier mill between August 19 and September 3, 1963 due to mill

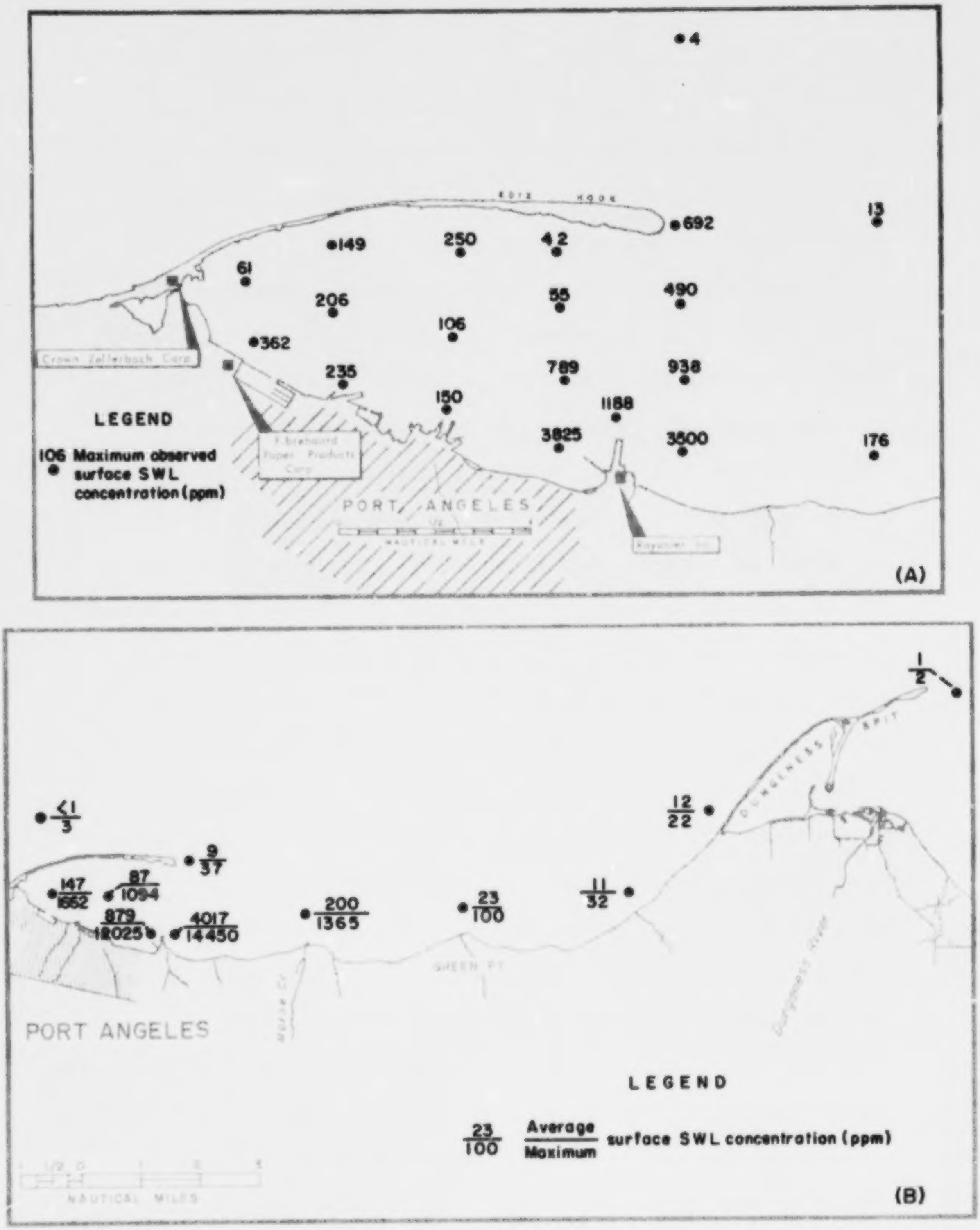

EDIZ HOOK
4
13
692
149
250
42
61
206
55
490
106
362
235
789
938
150
1188
3825
3500
176
Crown Zellerbach Corp.
Fibreboard Paper Products Corp.
Rayonier Inc.
LEGEND
106 Maximum observed surface SWL concentration (ppm)
PORT ANGELES
NAUTICAL MILES
(A)
1/2
DUNGENESS SPIT
12/22
<1/3
9/37
147/1662
87/1094
879/12025
4017/14450
200/1365
23/100
11/32
GREEN PT.
Morse Cr.
Dungeness River
PORT ANGELES
LEGEND
23/100 Average/Maximum surface SWL concentration (ppm)
1/2 0 1 2 3
NAUTICAL MILES
(B)

FIGURE 34-7. (A) Distribution of maximum observed surface SWL concentrations in the Port Angeles area; data from oceanographic studies, September 1962 to January 1964 and from plankton ecology studies, July 1963 to June 1964. (B) Distribution of average and maximum surface SWL between Ediz Hook and Dung Dungeness Spit; data from oyster larvae bioassay studies, May 1963 to July 1965.

closure by a labor strike; thus, the only pulp mill wastes discharged into the Harbor during this period were those from Fibreboard mill. Waste distribution observed on August 30, eleven days after Rayonier closed operations, is shown in Figure 34-8 by the vertical distribution of SWL along a north-south transect and the surface SWL pattern. Comparison of these patterns with the distributions of average SWL in the Harbor described previously (see Figure 34-6) show (1) Fibreboard wastes are prominent only in the inner portion of the Harbor, (2) the main portion of the Harbor has been flushed of nearly all wastes at all depths, and (3) in the absence of pulp mill wastes, background readings of SWL approach zero.

The mass of SWL contained within the Harbor during the August 30 survey is estimated at 1,730 tons, equivalent to the amount of SWL discharged by Fibreboard mill in 2.0 days (see Table 33-1). Thus, assuming that all wastes observed on August 30 were derived from Fibreboard discharge, the average flushing time of Fibreboard wastes out of Port Angeles Harbor at this time was also 2.0 days.

Water Quality in Port Angeles Harbor. The principal effect of pulp mill wastes on water quality in the Port Angeles area is the presence of sulfite waste liquors in concentrations potentially toxic to marine life. Average surface SWL concentrations in the Harbor (Figure 34-6B) exceed 15 ppm essentially over the entire area and exceed 50 ppm in about 50% of the area. Maximum observed surface SWL concentrations (Figure 34-7A) exceed 1,000 ppm within a one-half mile radius of Rayonier outfall and, during the juvenile salmon studies (see Section 35), exceeded 25,000 ppm within about 100 yards of their

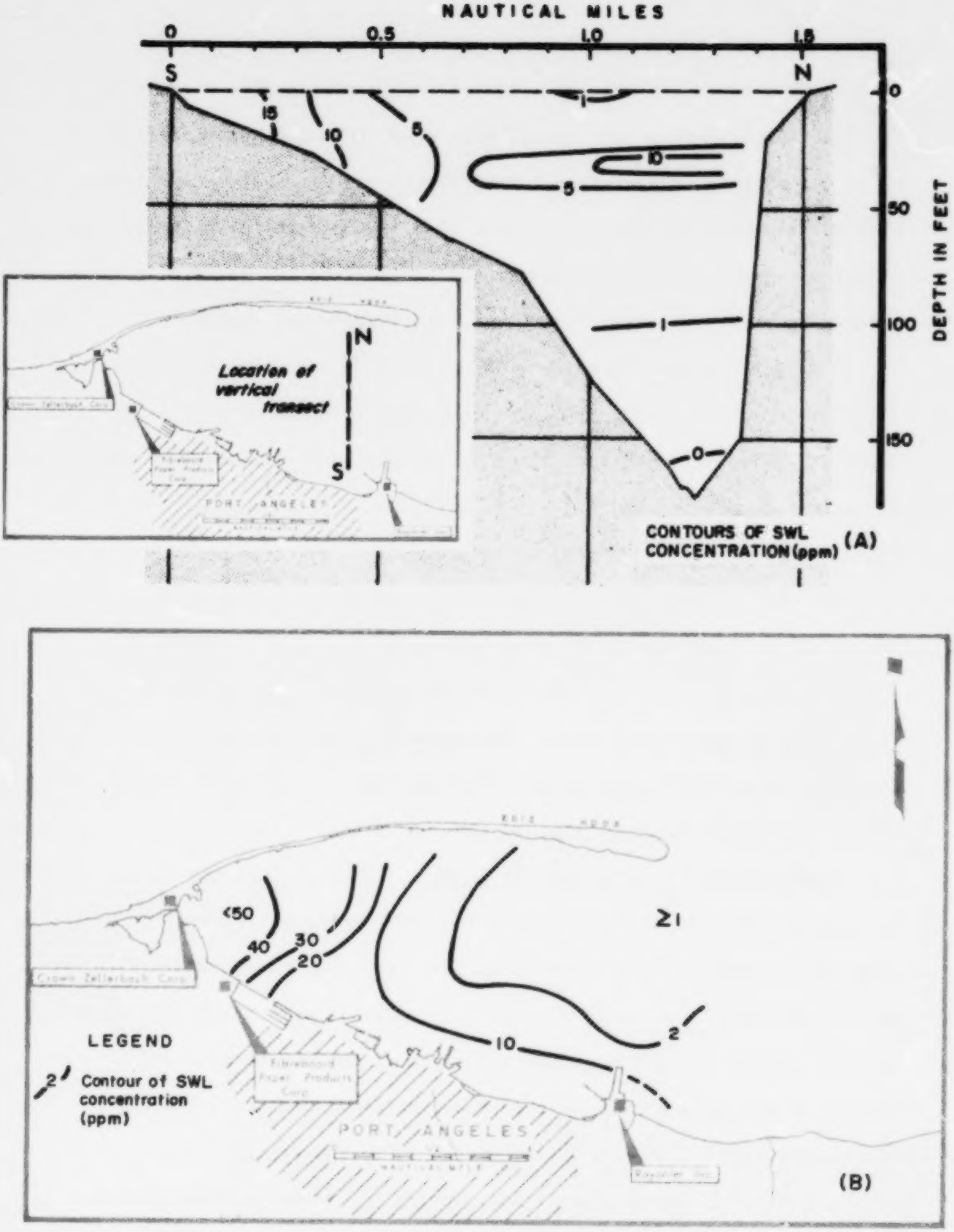


FIGURE 34-8. Distributions of SWL concentrations (A) along a north-south vertical transect within the Harbor entrance, and (B) at the surface in the Harbor; August 30, 1964.

outfall. About two and a half miles east of the Harbor entrance (Figure 34-7B) the average and maximum surface SWL values were 200 ppm and 1,365 ppm, respectively. Average SWL was 12 ppm near the base of Dungeness Spit, more than 10 miles from the Harbor. The extent to which these concentrations are harmful to marine life is presented in following sections (also see Parts II, III, and IV).

Other water quality properties in the Harbor are variably influenced by pulp mill wastes; Figure 34-9 shows a typical surface pattern of correlation between increasing SWL concentrations and decreasing water quality in terms of DO, pH, and water transparency. Surface DO in the southern portion of the Harbor averages about one mg/l less than "control" DO in the Strait of Juan de Fuca. Low DO values do occur, however; fifteen percent of surface samples taken along a 0.3 mile radius from Rayonier outfall had DO values less than 5 mg/l. On the other hand, surface pH values in the Harbor generally showed only slight depression except in areas immediately adjacent to the outfalls.

Water quality data taken during the juvenile salmon bioassay (see Table 35-2) show that serious water quality degradation--SWL values above 800 ppm, DO approaching zero, pH depressed, and presence of sulfides--occurs in the dockfront areas near each of the three pulp mills.

Bottom Deposits. Natural sediments in Port Angeles Harbor vary from gravel and coarse sand near the shoreline to homogeneous, olive-green colored, odorless muds which cover most of the Harbor floor. In some parts of the Harbor the upper inch of mud is brownish color, containing abundant mud balls and worm castings. In the southern and

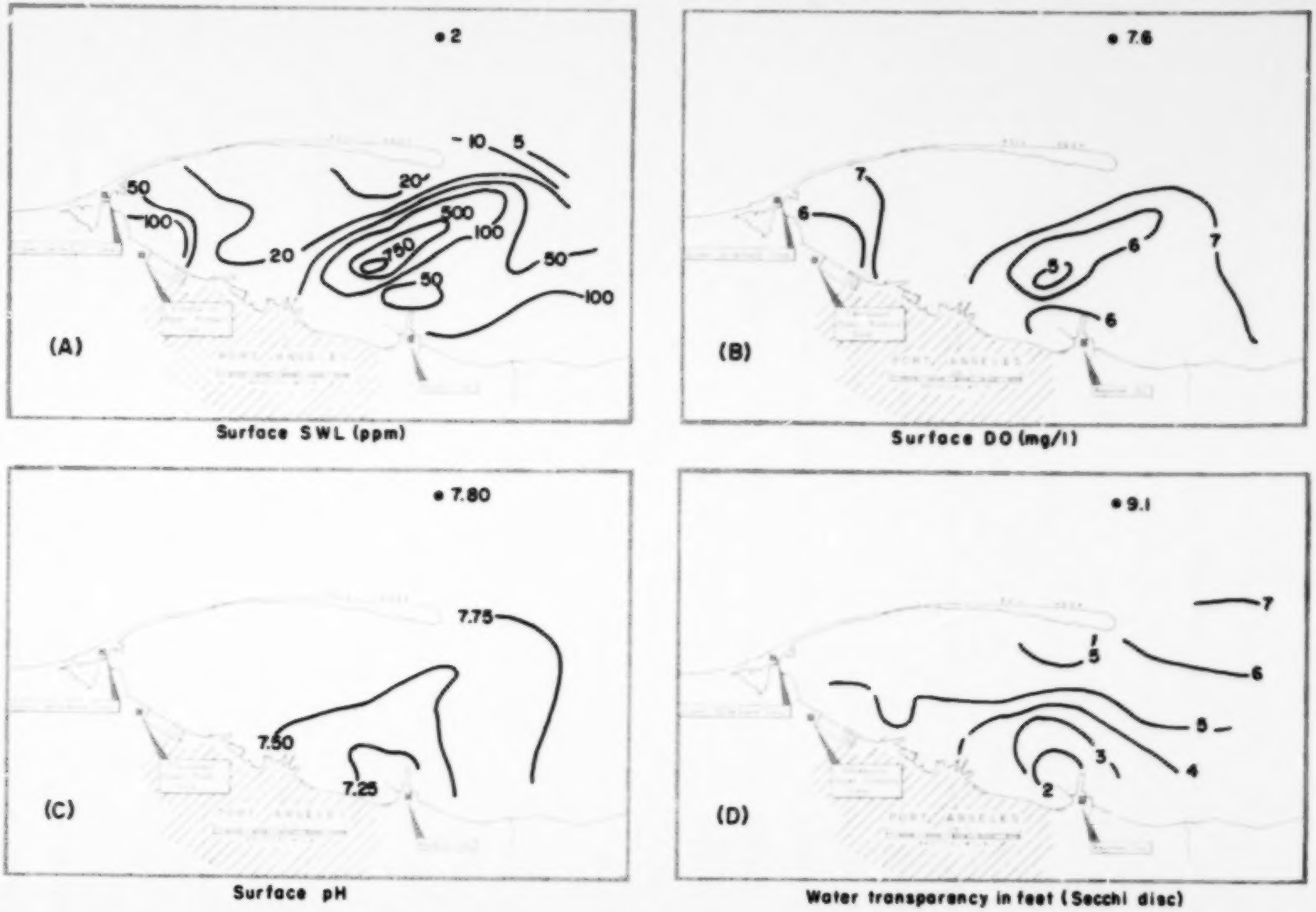

(A)
• 2
50
100
20
20
10
5
500
750
100
50
50
100
Surface SWL (ppm)
(B)
• 7.6
7
6
5
6
6
7
Surface DO (mg/l)
(C)
• 7.80
7.75
7.50
7.25
Surface pH
(D)
• 9.1
7
5
6
5
4
3
2
Water transparency in feet (Secchi disc)
PORT ANGELES

FIGURE 34-9. Patterns of (A) surface SWL, (B) surface DO, (C) surface pH, and (D) water transparency observed in the Port Angeles area on December 10, 1963.

western portions of the Harbor, natural sediments are overlain by extensive sludge beds mainly associated with pulp mill operations. The sludge consists of two types: a brownish-black to black, fine-grained, flocculent material smelling of hydrogen sulfide (H_2S); and a light grey-colored mass composed mainly of wood fibers and also having a strong H_2S odor.

The distribution and thickness of the sludge deposit is shown in Figure 34-10A; the zero contour represents a diffuse boundary beyond which no trace of sludge or H_2S odor were detected. The Harbor area enclosed by this zero contour is about 7 million square yards, or slightly more than 2 square miles. Total volume of sludge contained in the Harbor within the limits of the one-inch thickness contour is approximately 280,000 cubic yards. The sludge layer is thickest--16.5 inches--at the western end of the Harbor where currents are too weak to disperse settleable wastes before sedimentation. Most of this particular accumulation primarily resulted from past discharge of paper mill wastes to the Harbor by Crown Zellerbach mill; this effluent since has been rerouted to the Strait (see Section 33) but the sludge bed remains. Another area of appreciable sludge layer thickening surrounds Rayonier mill where a maximum sludge depth of 14.5 inches was measured. Chunks of floating sludge, buoyed to the surface by gases of decomposition and smelling of H_2S, have been frequently observed in both of these areas.

The distribution pattern of percent volatile solids in the Harbor surface sediments (Figure 34-10B) resembles that of the sludge distribution (Figure 34-10A) except for the noticeable volatile solids build-up

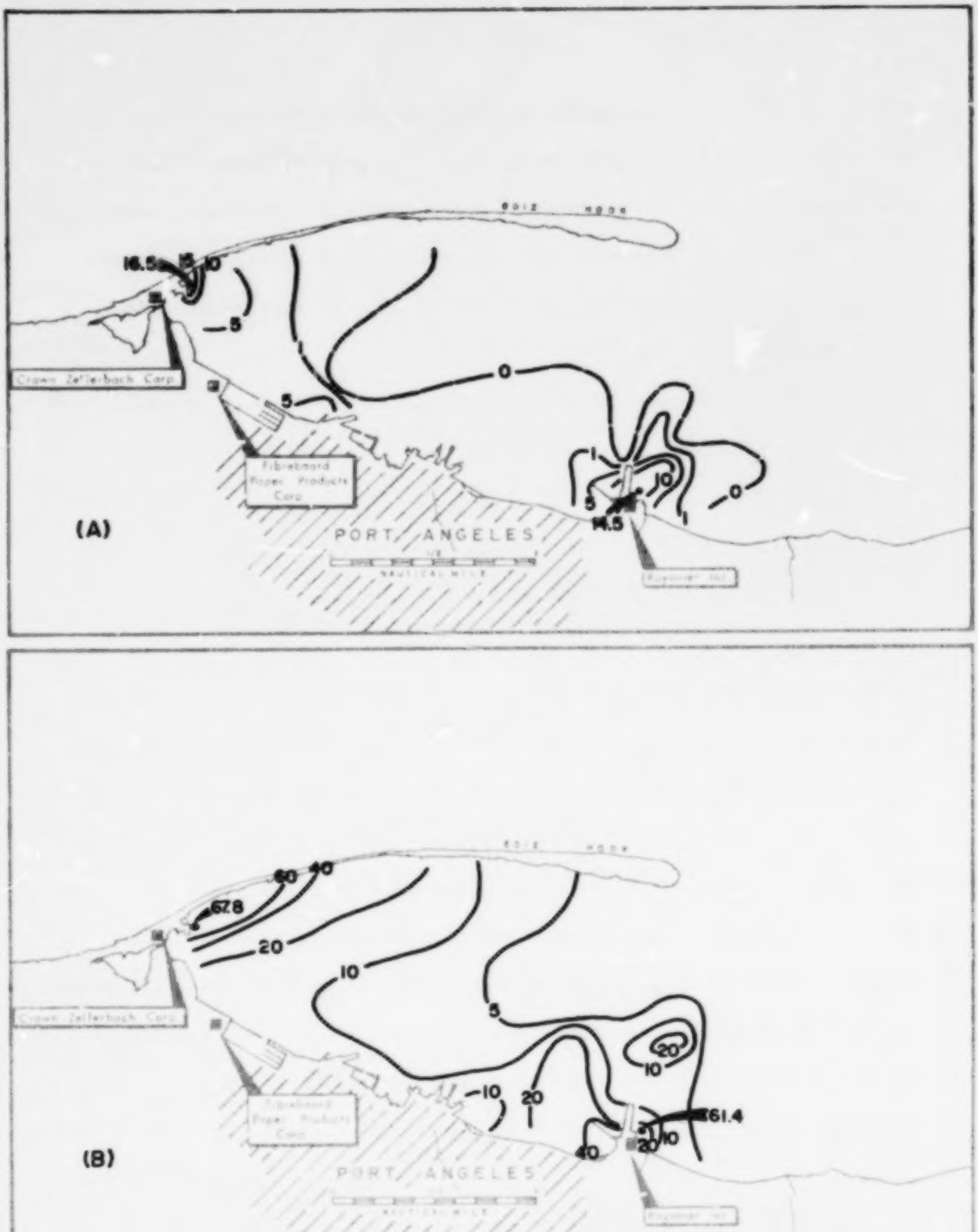

EDIZ HOOK
16.5
15
10
5
0
1
14.5
Crown Zellerbach Corp.
Fibreboard Paper Products Corp.
Rayonier Inc.
PORT ANGELES
NAUTICAL MILE
(A)
67.8
60
40
20
10
5
61.4
(B)

FIGURE 34-10. (A) Thickness in inches and areal distribution of sludge deposits, and (B) distribution of percent volatile solids in the sludge and bottom sediments in Port Angeles Harbor; September 30, 1964.

along the western portion of the north shore. This particular build-up, in large part, is due to extensive log-rafting operations in that area.

DISCUSSION

The natural landforms of Ediz Hook and Dungeness Spit transform currents in the Strait of Juan de Fuca into a variable, but predominantly anticlockwise, eddy-system of water circulation between Port Angeles Harbor and the Spit. Consequently, pulp and paper processing wastes discharged by the Fibreboard and Rayonier mills are dispersed mainly through the southern portion of the Harbor and eastward alongshore toward Dungeness Spit. Because of the eddy-nature of the circulation and limited depths in the dispersal zone, dilution of these wastes within the system is not sufficient to prevent adverse effects on water quality. Within the Harbor, the discharge of strong wastes results in substantial water quality degradation and settleable solids accumulation surrounding both the Fibreboard and Rayonier outfalls. Further, currents are too weak to scour and remove the extensive sludge bed formed at the western end of the Harbor by the now-discontinued discharge of high-solids wastes from Crown Zellerbach's paper mill. Outside the Harbor, the confining eastward eddy-circulation of wastes, particularly those from Rayonier mill, results in waste concentrations in the system well above those found to be seriously damaging to the marine environment. In summary, the hydraulic characteristics of the Port Angeles Harbor-Dungeness Spit eddy system are not adequate to accept the large volumes of strong pulp and paper processing wastes without resulting in serious pollution of the system.

In following sections are described the types and degrees of waste-attributed damages to marine life now occurring in the study area. Each section presents water quality criteria and abatement measures for prevention of such damages. In preview, adequate abatement will require significant reduction in SWL concentrations throughout the system, physical removal of existing sulfide-producing sludge beds, prevention of further solids accumulation, and maintenance of tolerable levels of DO and pH in the Harbor. Significantly, these measures must be met primarily by treatment of the wastes for removal of settleable and volatile dissolved solids, rather than by changes in disposal practices. Because of the presence of the large eddy system and its confining effect on wastes, a change in outfall location to any reasonable site within the Harbor or eastwards alongshore would simply relocate the damaging effects rather than remove them as required. There is not sufficient depth available at reasonable locations within the system to provide for adequate dilution of wastes by disposal through a deep-water diffuser outfall. Also, currents are too weak and variable to insure prevention of sludge accumulation at reasonably located outfall sites. In conclusion, local hydraulics makes the Port Angeles Harbor-Dungeness Spit eddy system unsuitable for the disposal of untreated wastes from the Fibreboard and Rayonier mill operations. Thus, compliance with the water quality criteria and abatement measures must be effected by adequate treatment of mill wastes prior to discharge.

35. JUVENILE SALMON

The Elwha and Dungeness Rivers, Morse Creek, and other smaller streams tributary to the Strait of Juan de Fuca in the Port Angeles area (see Figure 32-2) are natural spawning and rearing grounds for the several species of salmon and anadromous trout common to Puget Sound. Some of these streams also are planted with hatchery-reared salmon. Accordingly, during the spring and summer months, juvenile salmonids migrate from these streams and move into and through the subject study area, including Port Angeles Harbor. Port Angeles Harbor, however, is polluted by waste discharges from the Rayonier and Fibreboard mills and by sludge deposits formed from waste solids discharged by these mills and, previously, by the Crown Zellerbach mill (see Section 34). Therefore, water of a quality inimical to young salmon occurs in parts of the Harbor, and for this reason, the Washington Pollution Control Commission (WPCC) undertook juvenile salmon occurrence and bioassay studies in these waters during April and May 1964.

STUDIES

Occurrence Study. Beach-seine sampling was employed to determine the occurrence of juvenile salmon in the Harbor. Samples were regularly taken at the seining stations depicted in Figure 35-1. In addition, estimates of the number of young salmon seen at these stations and in the Boat Basin (Figure 35-1) were recorded.

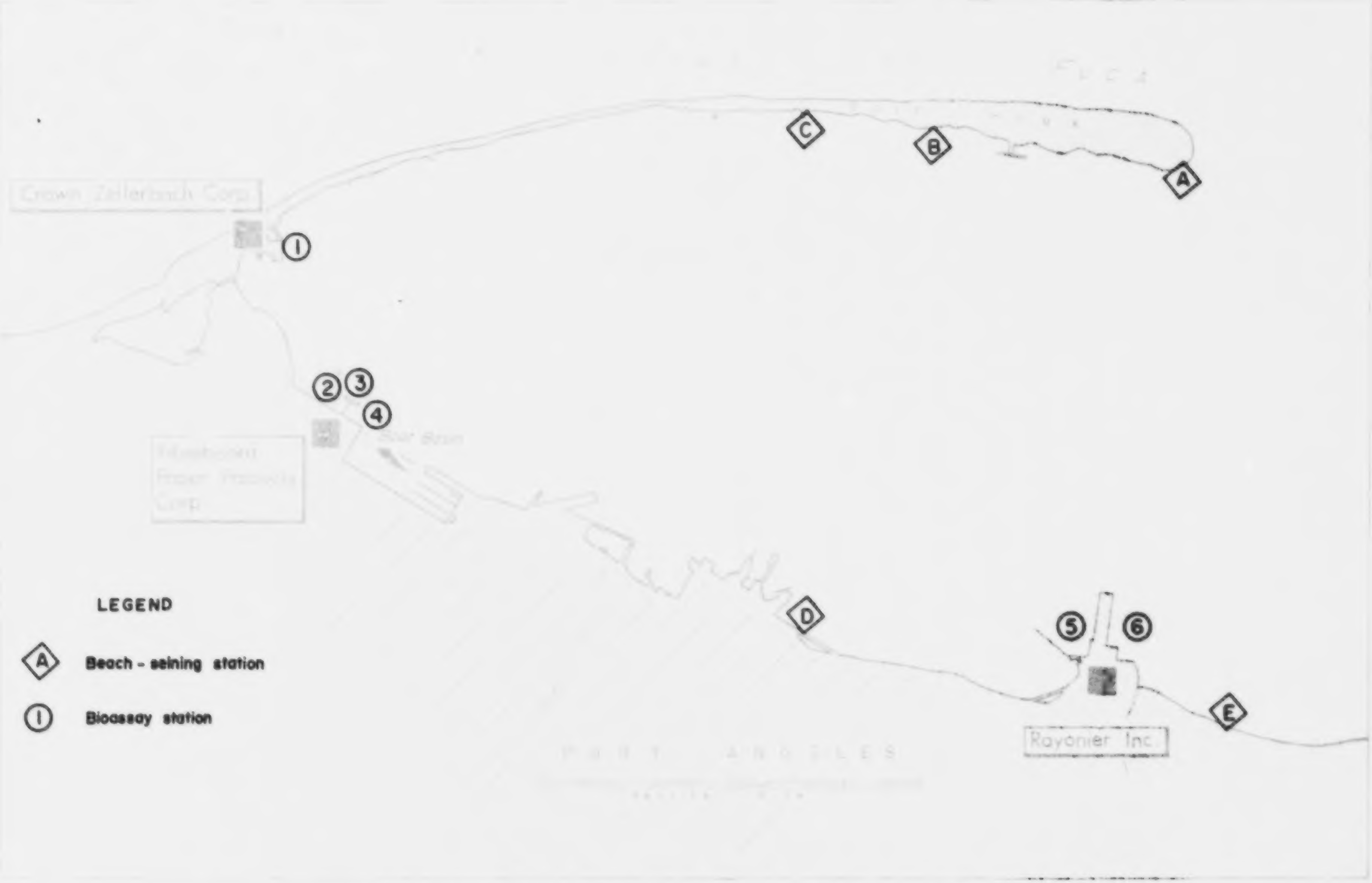

Crown Zellerbach Corp.
①
②
③
④
Boat Basin
Paper Products
Corp
Ⓐ
Ⓑ
Ⓒ
Ⓓ
Ⓔ
⑤
⑥
Rayonier Inc.
PORT ANGELES
LEGEND
Ⓐ Beach - seining station
① Bioassay station

FIGURE 35-1. Beach-seining and bioassay stations in Port Angeles Harbor.

Bioassay Study. Thirteen bioassays were conducted in the Harbor to determine the incidence and causes of conditions deleterious to juvenile salmon. These were conducted at the six bioassay stations also shown in Figure 35-1. In each test, concurrent *in situ* bioassays were run in the live tank of a floating lab (on station) and in each of five or six perimeter live boxes located in the vicinity of the station but 50 to 300 feet away from the floating lab. In each bioassay, ten test fish were placed in the live tank or live box and were exposed in the near-surface water for a period of 2½ to 4½ hours, unless a 100% kill terminated the bioassay in less than 2½ hours. At the floating lab, test-fish behavior and mortality were continuously observed and water samples (pumped from inside the live tank) were collected at intervals of 20 minutes or less. The live boxes were visited less frequently to observe the condition and mortality of test fish. With one exception, water samples were not collected at the live boxes.

METHODS

Occurrence Study Methods. Beach-seine samples were taken with a 100 x 6-foot, bag-type net. For each sample, hauls parallel to the shoreline for about 100 feet were made. Fish captured were identified and counted.

Bioassay Methods. Fish used in Tests A, C, D, G, H and I were pink salmon fry. In other tests, both pink and chum salmon fry were employed. These fish were collected in an area unaffected by high concentrations of mill wastes or by sludge deposits (along the Ediz Hook shoreline between Station A and C--Figure 35-1) and were kept in a holding box near Station C for at least 24 hours before use. Only those fish in good condition were used in the tests, and none was used more than once. Handling techniques were the same as those described in Section 8.

The floating lab used is described in Section 25 and pictured in Figure 25-3. The live boxes used for perimeter bioassays are described in Section 8 and illustrated in Figure 8-4.

Water samples collected from inside the live tank of the floating lab were analyzed for temperature, DO, pH, total sulfides, and salinity by the methods described in Section 25. In addition, SWL (10% solids) was determined by the modified Pearl-Benson method (Barnes, et al.; 1963). Except for salinity and SWL which were analyzed in the laboratory, analyses were made on the float immediately after collection.

RESULTS

Occurrence of Juvenile Salmon in the Harbor. Results of beach-seine sampling and visual observations of fish in Port Angeles Harbor are tabulated in Table 35-1. These data evidence the occurrence of young salmon, particularly chum and pink fry, in the Harbor and even in the vicinity of the Rayonier mill where pulp wastes substantially affect water quality.

Bioassay Mortalities and Associated Water Quality. Results of the 13 bioassay tests are summarized in Table 35-2. These data are arranged by area, and within each area-grouping, are arranged into the categories. (1) data from tests wherein 100% mortality occurred at the floating lab, and (2) data from tests in which no mortality occurred

TABLE 35-1. Numbers of juvenile salmon and other fish caught or seen in Port Angeles Harbor, April-May 1964.

Station	Species	Total Number Caught by Beach Seining	Estimated Number Visually Observed
A	Pink and Chum	419	50
	Chinook	2	
	Silver	1	
B	Pink and Chum	2	
C	Pink and Chum	349	1,100
D	Pink and Chum	78	1
	Smelt	50	
	Starry Flounder	1	
E	Pink and Chum	205	
	Sea-run Cutthroat	4	
	Starry Flounder	4	
	Smelt	*	
Boat Basin	Pink and Chum		35

* Smelt were consistently captured at this station but were not counted.

at the floating lab. The water-quality data for each test are derived from the water samples collected at the floating lab; no samples were taken at the perimeter live boxes but for the single exception footnoted. The mortalities observed in the perimeter live-boxes during each test also are given.

TABLE 35-2. Percent mortality at termination of bioassays and summary of associated water quality data, 1964 bioassay study in Port Angeles Harbor.

Test No.	Area of	Station	Date	Mort. (%)	Exposure Time		Total Sulfides (mg/l)		DO (mg/l)		SWL (ppm)		pH		Mortalities in Perimeter Live-Boxes (%)					
					(hrs)	(mins)	Max.	Med.	Min.	Med.	Max.	Med.	Min.	Med.						
A	Crown Zellerbach mill	1	4/22	100	0	12	0.9	0.9	6.4	6.4	- -	- -	6.8	6.8	100	20	0	0	0	- -
B		1	5/27	100	0	52*	2.8	0.6	2.8	4.5	94	94	6.9	7.1	100	100	20	10	0	- -
C		1	4/22	0	3	10	0.1	0.0	3.7	6.1	20	20	7.4	7.6	- -	- -	- -	- -	- -	- -
D		1	4/23	0	4	00	tr.	0.0	5.7	6.7	813	222	7.3	7.7	0	0	0	0	0	- -
E	Fibreboard mill	2	5/26	100	1	20	0.7	0.0	0.0	3.4	1320	711	6.4	6.5	100	100	100	100	100	- -
F		2	5/26	100	0	20	0.7	0.4	3.6	4.5	1010	1010	6.9	6.9	- -	- -	- -	- -	- -	- -
G		2	4/28	0	3	40	tr.	0.0	5.2	5.8	627	286	7.1	7.4	100	10	0	0	0	- -
H		3	4/30	0	3	00	0.0	0.0	5.4	6.2	593	151	7.3	7.7	10	0	0	0	0	0
I		4	4/29	0	2	33	0.2	0.1	5.3	5.6	96	66	7.6	7.6	100**	10	0	0	0	- -
J	Rayonier mill	5	5/14	100	0	20*	0.9	0.7	3.6	3.7	118	118	7.2	7.3	100	100	0	0	0	0
K		5	5/14	100	0	16	0.8	0.8	3.4	3.7	67	67	7.2	7.2	- -	- -	- -	- -	- -	- -
L		6	5/13	100	1	40	tr.	0.0	0.0	2.5	8870	2680	5.9	6.3	80	70	30	30	30	0
M		6	5/13	100	0	20	0.5	0.3	0.0	1.8	2270	2270	4.0	5.3	- -	- -	- -	- -	- -	- -

* Exposure time between first observation of test-fish distress and detection of total sulfides, and observation of 100% mortality.

** A total sulfides concentration of 0.3 mg/l was measured at this live-box shortly after observation of 100% mortality.

Note: Salinity and temperature showed little variation during tests and between tests. Median salinities ranged from 29.6 to 31.5 °/oo. Median temperatures ranged from 8.0 to 13.6 °C.

The mortality data in Table 35-2 evidence the frequent occurrence of toxic conditions in the vicinity of each of the three mills. In the vicinity of the Crown Zellerbach mill, 26% of all bioassays (including both floating-lab and live-box bioassays) yielded 100% kills; in the vicinity of the Fibreboard mill, 33% of all bioassays resulted in 100% kills; and near the Rayonier mill, 37% of all bioassays resulted in 100% kills. With but two exceptions (both 100% kills in Test A), these complete kills occurred during minus tides. These kills occurred very rapidly, and each was preceded by a period when the test fish exhibited severe distress and loss of equilibrium. Note, that in the floating-lab bioassays, five 100% kills occurred after exposure periods of 20 minutes or less, and all 100% kills occurred within exposure periods of 100 minutes or less.

The water quality data in Table 35-2 indicate that sulfides were the principal cause of the mortalities observed. With but one exception (Test L), all 100% kills in the floating-lab bioassays were associated with total sulfides of 0.3 mg/l or more. On the other hand, complete survival of test fish only occurred when observed maximum concentrations of total sulfides were 2 mg/l or less. In several of the sulfide-associated kills, other factors may have contributed to the fatalities noted; i.e., dissolved oxygen concentrations were significantly low in Test B, and DO became depleted in Tests E and M; SWL concentrations were significantly high in Tests E, F, and M; and pH was significantly low in Test M. In Test L, in which only a trace of total sulfides was detected, depletion of dissolved oxygen and exceedingly high SWL concentrations were probably the cause of mortality noted at the floating lab. During this test, the test fish reacted much differently than in other tests; viz., they surfaced, acted sluggish, and displayed jerking movements; and accumulative mortality, rather than proceeding rapidly, increased slowly but continuously throughout the exposure period.

DISCUSSION

The finding of juvenile salmon and other fish in Port Angeles Harbor demonstrates their natural utilization of these waters. Furthermore, the bioassay results show that, even in those parts of the Harbor most affected by sludge deposits and waste discharges from the Rayonier and Fibreboard mills, water quality is frequently adequate for the survival of young salmon; i.e., complete survival was observed in 50% of the bioassays conducted near these mills (Table 35-2). Consequently, it is concluded that juvenile salmon at times migrate into and through Port Angeles Harbor without being inhibited by the water quality therein.

Bioassay results in Table 35-2 also show, however, that water acutely toxic to juvenile salmon can develop in the Harbor. The toxic conditions develop rapidly enough to entrap fish by causing immediate loss of equilibrium and inhibiting their ability to escape to waters of favorable quality. Rapid mortalities follow. It is concluded, therefore, that numbers of juvenile salmon and, possibly, other fishes are killed by polluted waters in the Harbor.

The water quality results in Table 35-2 implicate sulfides as the principal toxicants causing the bioassay mortalities noted. These data also indicate that depressed dissolved oxygen concentrations, high SWL concentrations, and low pH levels have additional adverse effects. Therefore, from this information and similar information presented in Sections 8 and 27, it is recommended that the following water quality criteria be met at all times and at all points in Port Angeles Harbor to provide for the protection of young salmon and other fishes in these waters:

Total sulfides	no detectable amount
DO	greater than 5 mg/1
SWL (10% solids)	less than 1,000 ppm
pH	greater than 6.5
Other toxicants	no detectable amount

To ensure that these criteria are met, it is further recommended that water quality throughout the Harbor be adequate for the survival and normal behavior of juvenile salmon during 4-hour in situ bioassays similar to the live-box tests described in Section 8.

The cause of toxic concentrations of total sulfides in Port Angeles Harbor are the sludge deposits formed from waste solids discharged by the Rayonier and Fibreboard mills and, previously, by the Crown Zellerbach mill (see Section 34 and Figure 34-10). This sludge undergoes anaerobic decomposition and, thereby, produces H_2S which affects surface-water quality, particularly during minus tides. Clearly, abatement of sulfide toxicity will require removal of existing sludge deposits and prevention of future accumulations through substantial reduction in the discharge of suspended solids into the Harbor by the Rayonier and Fibreboard mills.

The causes of the adverse effects of depressed dissolved oxygen concentrations, high SWL concentrations, and low pH levels are, primarily, the discharges of digester-strength sulfite waste liquor by the same two mills. Clearly, abatement of these problems will require the reduction or treatment of these wastes.

36. BOTTOM ORGANISMS

Settled waste solids from the Crown Zellerbach, Fibreboard, and Rayonier mills have accumulated to form extensive sludge deposits in Port Angeles Harbor, particularly in the western third of the Harbor and in the vicinity of the Rayonier mill (see Section 34 and Figure 34-10). For the reason that such deposits can have a deleterious effect on benthic fauna, the Project conducted a benthic study in the Harbor on September 30, 1964.

STUDY

Sediment samples, one from each station, were collected with a 0.25-cubic-foot van Veen dredge from the 31 stations shown in Figure 36-1. These were analyzed for percent volatile solids of the sediment, and the included bottom organisms were identified and their relative numbers estimated.

METHODS

Sampling and laboratory procedures were the same as described in Section 9; *i.e.*, gross appearance of the sample was noted and recorded, a portion was frozen and delivered to the laboratory for volatile solids analysis, and the remaining portion was preserved, stained, and delivered to the laboratory for examination of the benthos. Organisms were classified as to kind, each kind being a group of organisms having similar life zones and food habits. In each sample, the relative number of each kind was estimated; *i.e.*, abundant, common, few, scarce, rare, and none.

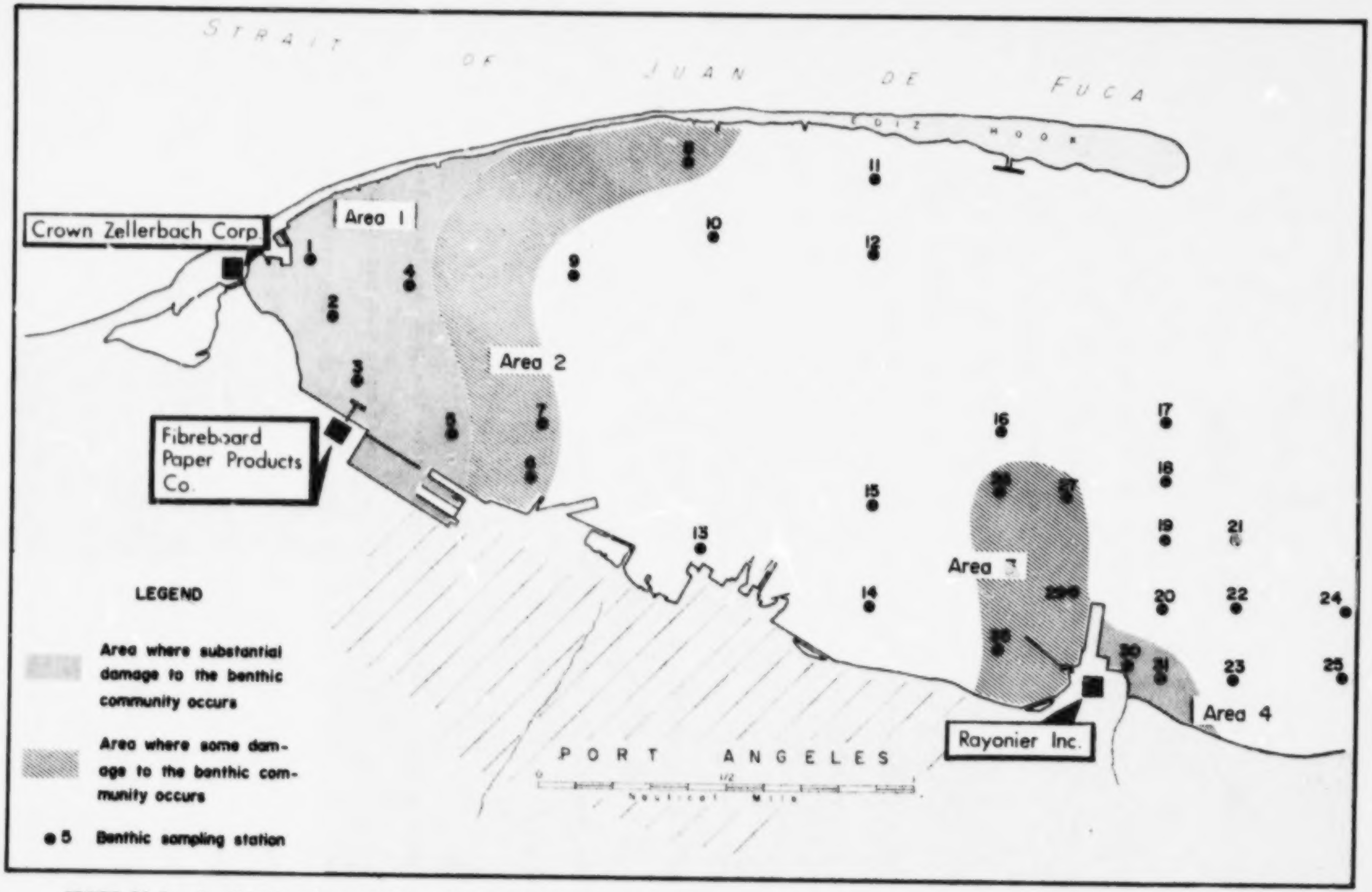

STRAIT OF JUAN DE FUCA
EDIZ HOOK
Crown Zellerbach Corp
Fibreboard Paper Products Co.
Rayonier Inc.
Area 1
Area 2
Area 3
Area 4
PORT ANGELES
0
1/2
1
Nautical Mile
LEGEND
Area where substantial damage to the benthic community occurs
Area where some damage to the benthic community occurs
● 5 Benthic sampling station
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31

FIGURE 36-1. Benthic sampling stations in Port Angeles Harbor on September 30, 1964; and areas of damage to the benthic community.

RESULTS

Results of the study are tabulated in Table 36-1. To provide a numerical estimate of the population densities, the relative-number categories were assigned rank numbers as described in the footnote of the table. Further, the data are grouped by area (see Figure 36-1), as indicated by differences among population densities, population diversities, and sediment volatile solids (values in the last three columns) of the areas.

Note in the Main Area of the Harbor (1) that population densities are moderate and fairly consistent as indicated by the range of total relative numbers from 8 to 17; (2) that population diversity is high and consistent as evidenced by the 4 to 7 range in kinds of organisms per sample; and (3) that percent volatile solids in the sediments are generally low, ranging from 3 to 10% except for three anomalous values. These data describe the natural and unaffected benthic fauna and sediment characteristics of the Harbor. In Areas 1, 2, 3, and 4, population densities and population diversities are significantly lower (95% confidence limit) and percent volatile solids of the sediments are significantly higher (95% confidence level) than respective values in the Main Area. These comparisons describe associated damage to the benthic fauna and accumulation of organic waste solids in the sediments in those portions of Port Angeles Harbor distinguished by shading in Figure 36-1. Furthermore, the data of Table 36-1 describe greater benthos damage and greater sludge disposition in Areas 1 and 4. Areas 2 and 3 appear to be transition zones from areas of substantial damage to the main area where little or no sludge effects are evident.

TABLE 36-1. Relative numbers and kinds of benthic organisms, and percent volatile solids in sediment samples collected in Port Angeles Harbor on September 30, 1964.

Area	Station	Relative Number* of Each Kind per Sample: Worms	Amphipods Isopods	Clams Snails	Copepods Ostracods	Crabs Shrimp Cumaceans	Moss Animals	Other	Total Relative Number* per Sample	Kinds per Sample	% Volatile Solids in the Sediment
1	1								0	0	68
	2								0	0	20
	3	1							1	1	14
	4	2		1					3	2	26
	5	2		1					3	2	16
2	6	3		1	1				5	3	19
	7	4	1	2					7	3	9
	8	2	4	1					7	3	21
Main Area of Harbor	9	4	2	4	2				12	4	18
	10	4	1	2	2				9	4	19
	11	5	3	1	1	1			11	5	9
	12	5		4	1	1	1		12	5	9
	13	4		2			1	1	8	4	10
	14	4	5	4	3				16	4	6
	15	4	1	1	1	3	1	1	12	7	5
	16	5	3	1	3				12	4	5
	17	4	4	3	4		1	1	17	6	5
	18	3	5	1		1			10	4	28
	19	3	5	2		1			11	4	7
	20	2	5	1		1			9	4	6
	21	4		3		2		1	10	4	5
	22	4	5		2		1		12	4	5
	23	3	5		3		3		14	4	5
	24	2	5	1		2	1		11	5	4
	25		5	1		2	1		9	4	3
3	26	2	3						5	2	21
	27	4	4	2					10	3	9
	28	3	4		5				12	3	27
	29	4	4	1					9	3	8
4	30								0	0	61
	31								0	0	7

* Assigned rank values are abundant (5), common (4), few (3), scarce (2), rare (1), none (blank or 0).

DISCUSSION

The total shaded area of benthos damage in Figure 36-1 covers, approximately, the same area as covered by sludge one inch thick and greater (Figure 34-10A), and as covered by sediments containing volatile solids of 10% and greater (Figure 34-10B). That the three mills--Crown Zellerbach, Fibreboard, and Rayonier--have been the principal sources of the waste solids that caused the described sludge deposit and biological damage is evident from the configuration of the referenced areas in all three figures. Furthermore, substantial quantities of pulp fiber were found in all samples collected in this sludge deposit.

Untreated domestic wastes also are discharged into the Harbor by the City of Port Angeles (see Figure 32-1). These contribute settleable solids to the sludge mass described, but this contribution is considerably smaller than that of the three mills combined; i.e., 1.2 tons per day vs. 53.5 tons per day of volatile suspended solids (see Tables 33-1, 33-2, and 33-3).

The largest area of sludge accumulation is in the western end of the Harbor (Areas 1 and 2, Figure 36-1). Weak circulation in the closed end of the Harbor and waste discharges by the Crown Zellerbach and Fibreboard mills contributed to this situation. The Crown Zellerbach mill has modified its in-plant sewer system and now discharges all wastes including solids-bearing wastes into the Strait of Juan de Fuca. However, continued waste discharge by the Fibreboard mill and little, if any, removal of accumulated sludge by the weak currents in this western portion of the Harbor serve to maintain this sludge deposit.

It is clearly evident that abatement of damage to the benthic fauna of Port Angeles Harbor will require the removal of existing sludge deposits and prevention of future sludge accumulation.

37. OYSTER LARVAE

Planktonic life stages of shellfish and other marine animals are found in the Port Angeles area. These planktonic forms are usually more susceptible to alterations of the environment than are later life stages, and the greatest and most subtle damage to a species may occur during the egg or larval stages. Although no commercial oyster grounds are present, a commercial and sport clam fishery is found along the beaches toward and past Dungeness Spit wherever suitable bottom materials occur. Dungeness crabs are taken throughout the area. To assess the potential damage to the early-life stages of marine organisms in the Port Angeles area, the Project conducted two investigations using Pacific oyster larva bioassays: (1) a field-sample oyster-larva response study and (2) a waste-sample oyster-larva response study.

STUDIES

The field-sample oyster-larva study in the Port Angeles area was conducted at 12 stations (Figure 37-1). Surface water samples were collected at these stations at monthly intervals between May 1963 and August 1964; additional samples were taken during the periods of July 6-9 and November 16-30, 1964, to evaluate water-quality changes during closures of the Rayonier and Fibreboard Products mills. Supplementary samples were collected on July 13, 1964, as checks on water quality and to provide additional "overlap" sampling.

The waste-sample oyster-larva response study was conducted on 24-hour composite samples of in-plant wastes from (1) three waste lines

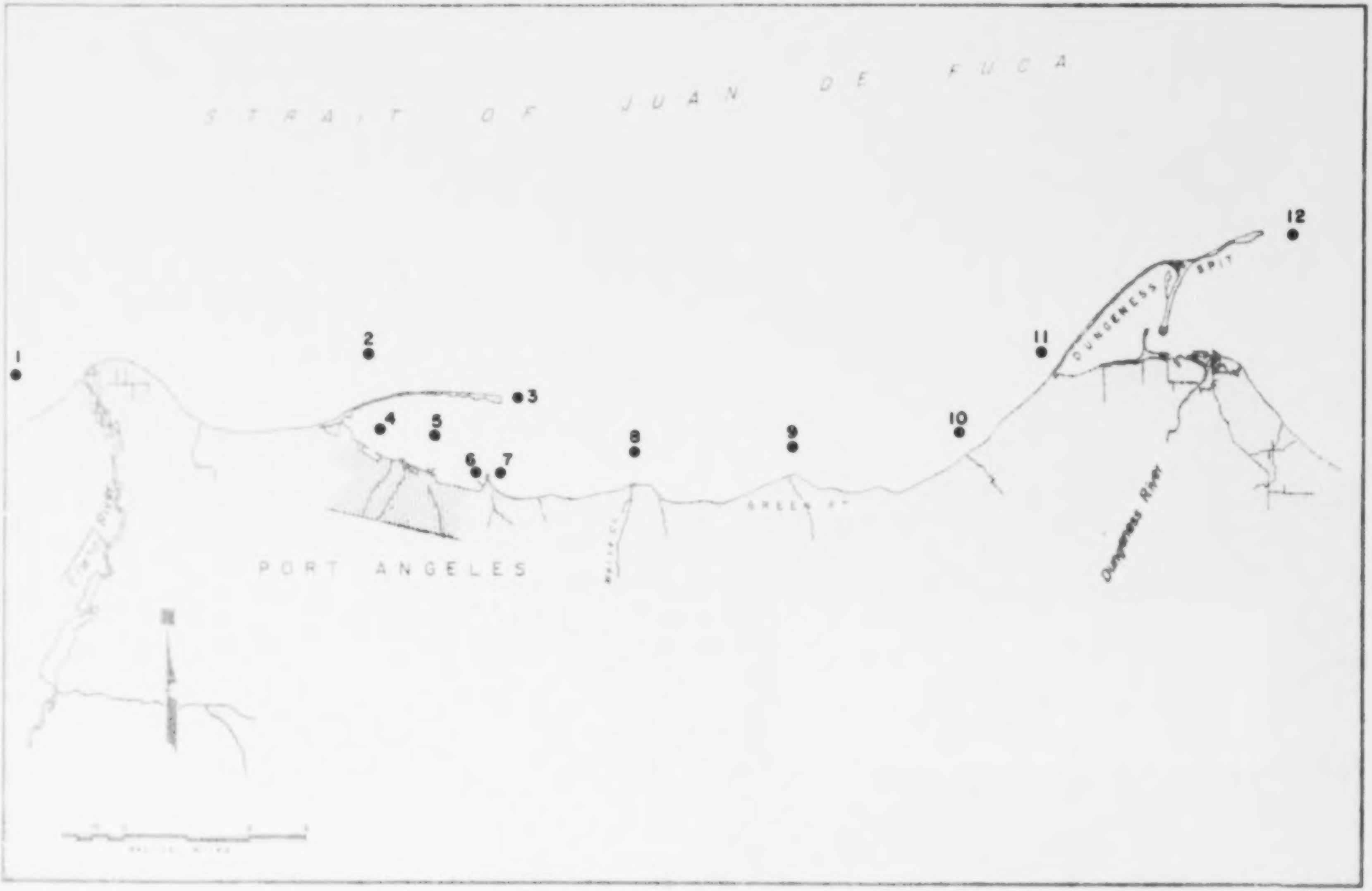

STRAIT OF JUAN DE FUCA
1
2
3
4
5
6
7
8
9
10
11
12
PORT ANGELES
DUNGENESS SPIT
Dungeness River

FIGURE 37-1. Water sampling stations, field-sample oyster-larva response study.

at the Rayonier pulp mill on June 9, 1964, (2) two waste lines at Fibreboard Products mill on April 22, 1964, and (3) four waste lines at the Crown Zellerbach mill on January 27, 1965.

All bioassays and associated laboratory analyses for both studies were performed or supervised by Charles E. Woelke of the Washington Shellfish Laboratory staff.

METHODS

The methods and procedures used in these studies are described in Section 11.

RESULTS

Results of Field-Sample Study. The results for the Port Angeles area are presented and discussed by Dr. G. J. Paulik, Biometrician, University of Washington School of Fisheries, in a final report (1966a). Descriptions of the statistical tests used are given by Paulik in four interim reports (1963, 1964, 1965a, and 1965b) and in the final report (*op. cit.*).

Bioassay-response results of the 16-month study are presented in Table 37-1. These results are based on data derived after removal of (1) samples having salinities of $20^{o}/oo$ or less, (2) samples bioassayed during the 1963-64 winter period, and (3) samples collected early on July 6, before waste flows began again after the July 4th holiday, and on November 16 and 23, 1964, when the mills were not operating because of a labor strike. The rationale for the removal of these samples is given in Section 11.

TABLE 37-1. Summary of results from the field-sample oyster-larva response study in the Port Angeles area, May 1963-July 1965. Data from samples with salinities of 20°/oo or less and samples collected during the 1963-64 winter period (October through March inclusive) and on July 6, 1964 and on November 16 and 23, 1964 are omitted.

Station Number (1)	Number of Field Samples (2)	Mean Percent Abnormal (3)	Mean Percent Net Risk (4)	Mean SWL Conc. (ppm) (5)	Mean Salinity (°/oo) (6)	Mean Intra-Sample Variance of Percent Abnormal (7)	Inter-Sample Standard Error of Mean Percent Abnormal (8)	Standard Deviation of SWL Conc. (9)	Standard Deviation of Percent Net Risk (10)
1	12	1.42	0.84	0.7	29.77	0.87	0.36	1.1	1.2156
2	9	1.85	1.30	1.0	30.76	1.01	0.66	1.0	1.8401
3	10	1.98	1.45	3.4	30.95	2.02	0.68	2.5	2.0459
4	12	81.82	81.78	250.3	30.35	1.84	10.52	474.3	36.5103
5	12	62.12	61.85	128.1	30.49	9.33	13.23	292.9	46.1782
6	10	90.11	90.04	1367.6	30.19	13.48	6.25	3758.2	19.9392
7	11	95.29	95.27	3865.5	27.94	70.54	1.79	4377.3	5.9469
8	9	86.80	86.75	269.8	30.08	123.77	9.50	460.6	28.6486
9	12	79.49	79.40	32.8	30.82	5.88	10.52	23.1	36.5891
10	7	32.42	32.03	15.3	30.88	87.93	12.65	8.8	33.6732
11	8	6.21	5.71	8.9	31.11	10.68	2.79	6.2	8.0115
12	9	9.27	8.78	0.9	30.68	61.77	8.08	0.7	24.3877

Table 37-1 and the discussion below, then, consider only those data derived from (1) samples not influenced by low salinities or poor test animals and (2) from those samples taken during normal mill operations which reflect the usual ranges of water quality and environmental conditions found in the study area.

In column 3 of Table 37-1, the response measure "mean percent-abnormal" is given for each station. These values, together with the mean SWL values, column 5, are shown (rounded) in Figure 37-2. Note that, in spite of the fact that the samples were taken over a wide variety of meteorological and hydrographic conditions, there are clear-cut differences between the individual stations. Further, a definite relationship is evident between mean percent abnormal and mean SWL concentration--mean percent abnormals increases with increases in SWL concentration. Note also that percent-abnormal values increase with decreasing distance from pulp mill waste sources. These relationships, together with observed decreases in SWL and abnormalities that followed mill closures and the increases in SWL and abnormalities following resumption of production, are evidence that pulping wastes affect oyster larva development and that the sources of these wastes are the pulp mills in Port Angeles.

Larval Abnormality vs SWL Concentration. Figure 37-3 shows the relationship between percent abnormals and SWL concentration. The method of deriving this logistic response curve is given in Section 11. Note that larval abnormality begins to increase very rapidly at SWL concentrations of about 10 ppm and that near-100% abnormality is reached at about 50 ppm. When this curve is compared to the curve of

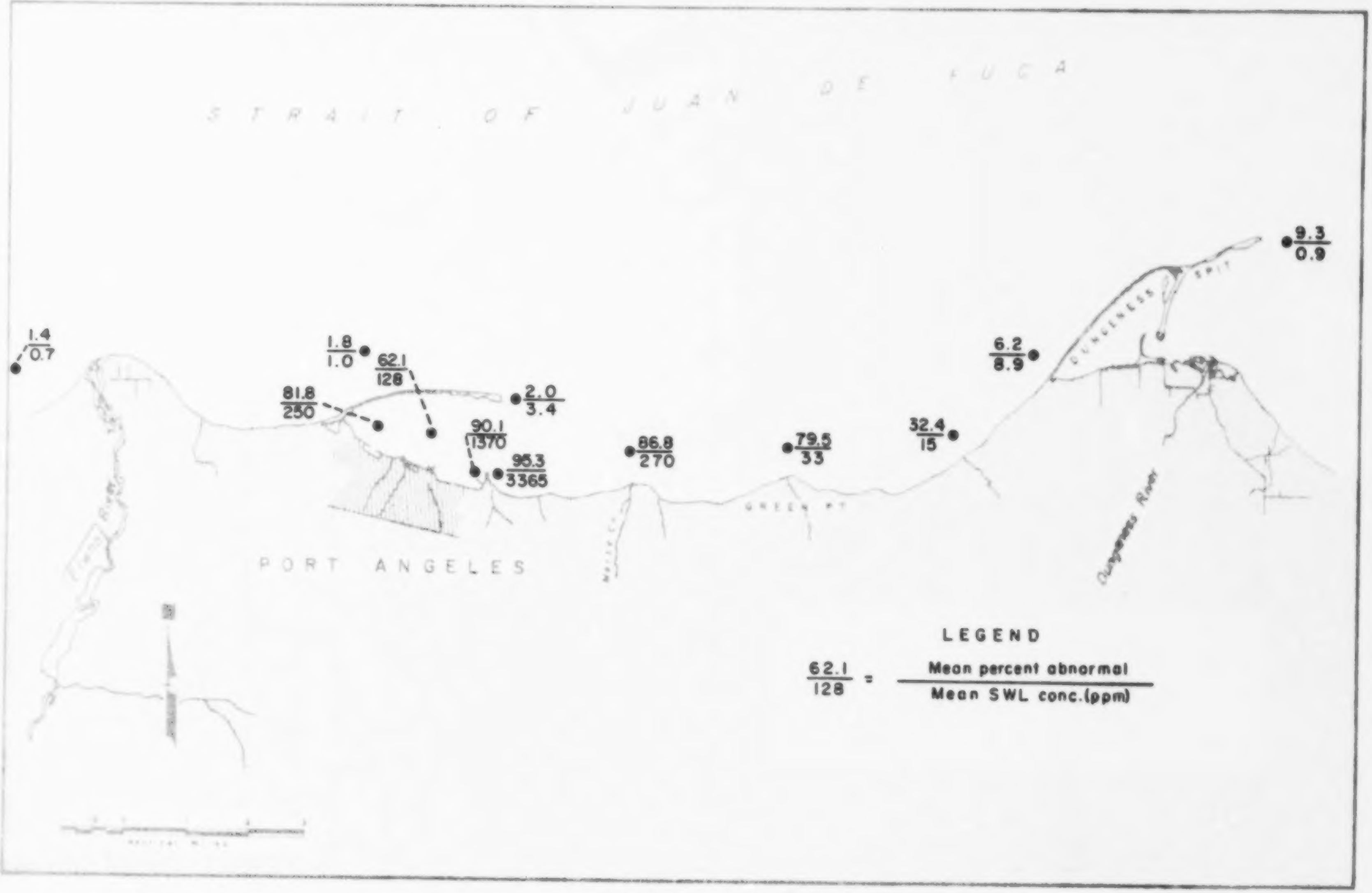

STRAIT OF JUAN DE FUCA
1.4
0.7
1.8
1.0
62.1
128
81.8
250
2.0
3.4
90.1
1370
95.3
3365
86.8
270
79.5
33
32.4
15
6.2
8.9
9.3
0.9
DUNGENESS SPIT
Dungeness River
GREEN PT
PORT ANGELES
LEGEND
62.1
128
= Mean percent abnormal
Mean SWL conc.(ppm)

FIGURE 37-2. Mean percent oyster-larva abnormality and mean SWL concentration at each field-sample station in the Port Angeles area; field-sample oyster-larva response study, May 1963 through July 1965 (see Table 37-1 for description of data removed).

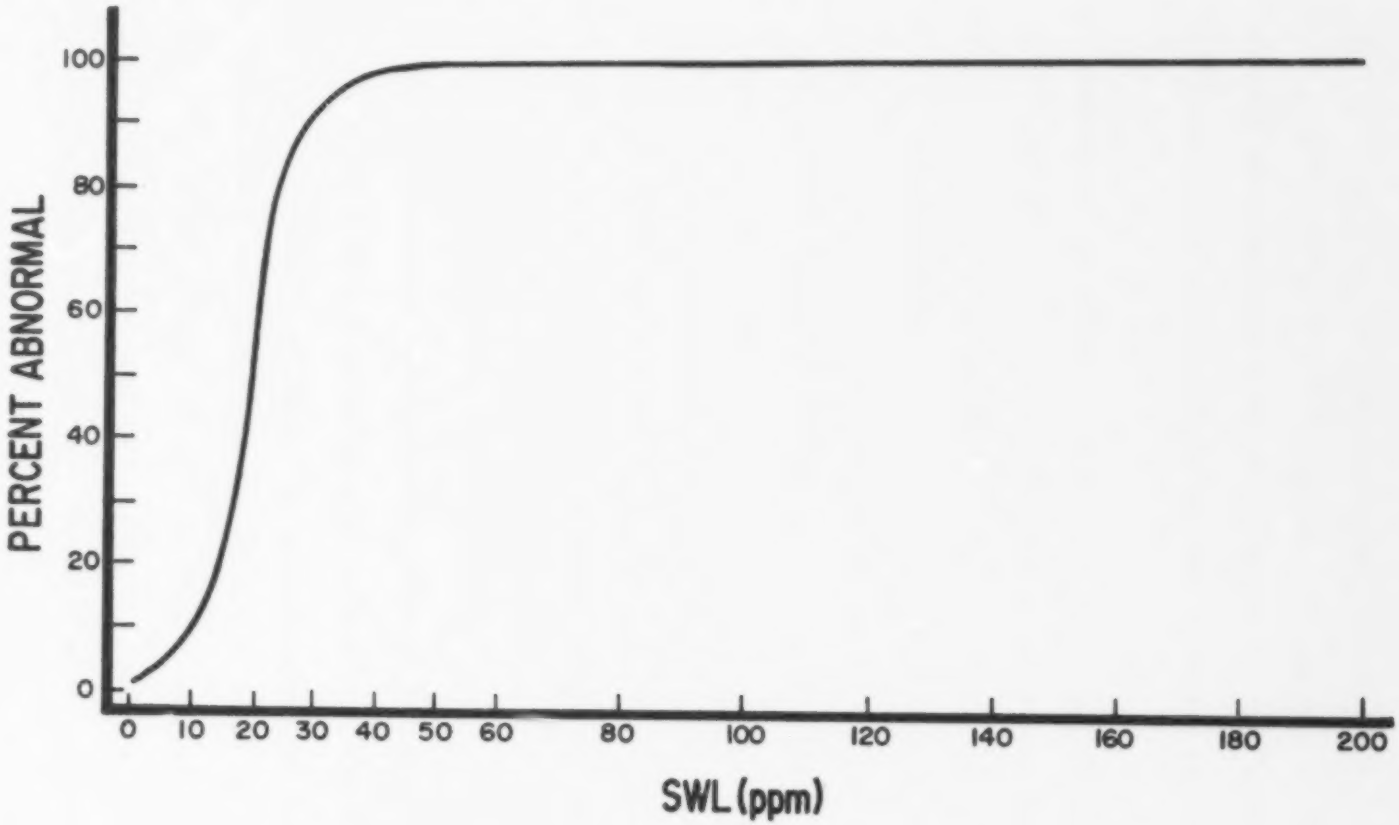


FIGURE 37-3. Percent larval abnormality vs. SWL, for the Port Angeles area.

the Bellingham-Anacortes area (Section 11) and that of the Everett area (Section 27) it is evident that the wastes of the Port Angeles area are intermediate in toxicity, being more toxic in the lower concentrations than the wastes of the Bellingham-Anacortes area but less toxic than wastes of the Everett area at similar concentrations of SWL.

Larval Abnormality in Controls. In Section 11 a comparison was made between laboratory controls, carry-along controls, and "field controls". The "field controls" are defined as samples that (1) had salinities greater 20°/oo; (2) were not collected during the 1963-64 winter period; and (3) had SWL concentrations of 2.0 ppm or less.

When these restrictions are applied to samples from the Port Angeles area, the results are as shown in Table 37-2. Note that the overall mean of control abnormals (bottom row) are about 2% and are significantly lower than the mean abnormal values found at stations where above-background concentrations of SWL were observed (Table 37-1). The field-control and carry-along-control abnormalities do not differ significantly from the laboratory-control abnormalities and strengthen the conclusion that the techniques used were both sensitive and valid for detecting the effects of pulping wastes on oyster-larva development.

Larval Abnormality During Mill Closure. A labor strike stopped production at all of the mills in Port Angeles during the period of November 12-26, 1964. In Table 37-3 the results from samples collected on November 16 and 23, during the shutdown, are compared with the overall mean results and those obtained on November 30, after resumption of production.

TABLE 37-2. Summary of the percent-abnormal values in the control bioassays of the field-sample oyster-larva response study in the Port Angeles area, May 1963 through July 1965. Data collected October 1963 through March 1964 excluded.

Month	Field Controls (SWL ≤ 2 ppm, Salinity > 20°/oo) No. Samples	Field Controls (SWL ≤ 2 ppm, Salinity > 20°/oo) Mean % Abnormal	Laboratory Controls Mean % Abnormal	Carry-Along Controls Mean % Abnormal
May 1963	1	2.21	1.28	- -
June	2	0.09	0.87	0.15
July	2	1.00	0.37	0.00
Sept.	4	2.72	0.57	0.27
April 1964	2	0.68	0.36	1.61
May	3	0.34	0.63	0.85
June	4	0.66	0.34	1.38
July	9	2.42	1.05[1]	1.04[2]
Aug.	1	2.60[3]	0.24	0.63
Nov.	16	2.78	2.71[1]	5.52[1]
July 1965	4	1.29	0.79	0.19
Over-all Mean (weighted)	- -	1.96	1.12	1.82

[1] Three samples
[2] Two samples
[3] One aberrant sample with 73.86% abnormal omitted

TABLE 37-3. Percent-abnormal and SWL values for samples at selected stations in the Port Angeles area on November 16 and 23, during mill closure, and November 30, after resumption of production, compared to overall means (all values rounded).

Station	Overall Mean SWL (ppm)	Overall Mean Percent Abnormal	November 16, 1964 SWL (ppm)	November 16, 1964 Percent Abnormal	November 23, 1964 SWL (ppm)	November 23, 1964 Percent Abnormal	November 30, 1964 SWL (ppm)	November 30, 1964 Percent Abnormal
1	1	1.4	1	9.2	0	0.4	0	3.2
4	250	81.8	5	14.7	1	1.0	56	100.0
5	128	62.1	4	12.0	0	0.5	20	100.0
7	3,865	95.3	4	6.8	0	1.3	5,275	100.0
8	270	86.8	2	10.8	0	0.4	652	100.0
9	33	79.5	1	7.4	0	1.3	28	100.0
10	15	32.4	2	5.0	0	0.4	12	29.5
11	9	6.2	2	4.9	1	0.7	8	5.7
12	1	9.3	1	4.8	1	1.7	0	2.4

This demonstration of the relationship between water toxicity and pulp mill operations is striking and unmistakable. Note that SWL values fell to 5 ppm or less at all stations by November 16, after about four days of little or no production, and to zero, essentially by November 23, after about 11 days. These data suggest a total flushing time of more than four days during this period and, also, clearly establish normal or "background" levels of SWL and percent-abnormal oyster larvae for the Port Angeles area; *i.e.*, less than 1 ppm SWL and less than 2% abnormals--about the same as laboratory controls.

The marked increase in SWL concentrations and in percent abnormal larvae at all polluted stations is noted on November 30, about five days after production was resumed. The probability that such an increase in SWL was due to chance is less than 0.05, and the probability that the increase in percent abnormals was due to chance is less than 0.005 (the same results would occur by chance less than five times in 1,000 occurrences). In both cases, the null hypothesis that the reopening of the mills did not affect either the SWL values or the percent of abnormal larvae is rejected. Results obtained from samples collected on July 6, 1964 (after the July 4th holiday closure), as compared with the results of June 22 and July 9, 1964 sampling, show similar relationships.

The percent abnormal and SWL values for November 23 in relationship to distances from the Port Angeles mills are shown in Figure 37-4. The near-complete flushing of the Port Angeles system after 11 days is evidenced by the low (background) levels of percent abnormals and SWL.

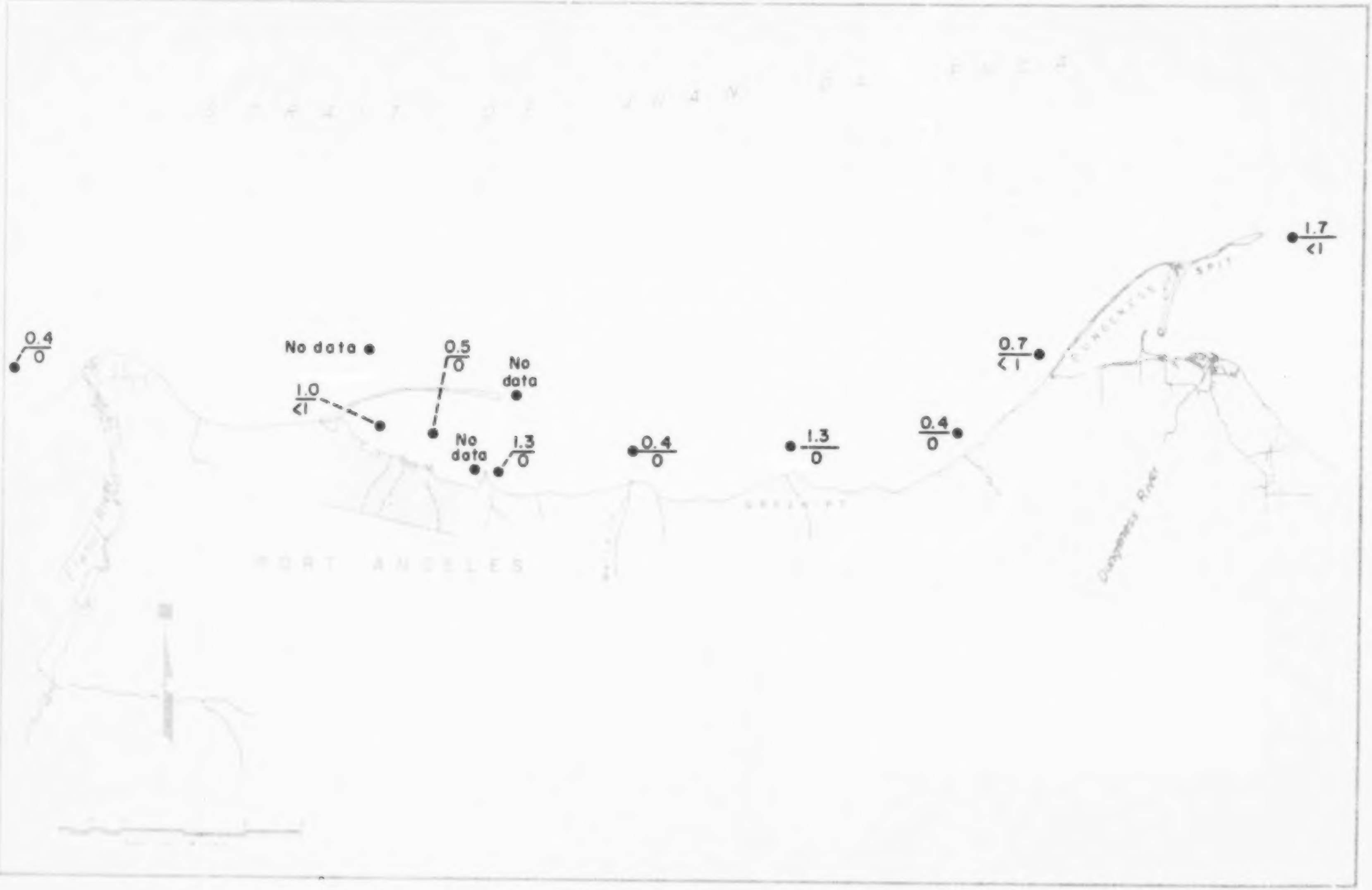

STRAIT OF JUAN DE FUCA
0.4 / 0
No data
1.0 / <1
0.5 / 0
No data
No data
1.3 / 0
0.4 / 0
1.3 / 0
0.4 / 0
0.7 / <1
1.7 / <1
PORT ANGELES
Dungeness River

FIGURE 37-4. Percent abnormal values and SWL concentrations from samples collected at selected stations in the Port Angeles area, November 23, 1964.

Results of the Waste-Sample Study. The results of this study, given below, are fully presented and discussed by Woelke in a report to the Project (1965, unpublished). The descriptions of methods used and data treatment are given in Section 11 of this report. Briefly, 24-hour-composite samples of wastes were serially diluted with fresh unpolluted seawater and were bioassayed with oyster larvae. The response measures--percent abnormal larvae--of the various dilutions of a waste were plotted on probit paper against the appropriate dilution ratios and SWL concentrations; from the line of best fit, dilution ratios and SWL values for the 0, 20, 50, and 100% abnormal levels were determined. These data are given in Table 37-4.

It is seen that the most toxic wastes are associated with chemical pulping processes although the SWL levels do not show any particular pattern when the data are arrayed by dilution ratios. In this regard, note that the pulping process employed by Crown Zellerbach is mechanical, and dissolved chemicals, lignins, wood sugars, etc., are in low concentrations in the mill's pulping wastes. These substances are produced to a degree in this mill's bleaching operation, however (see Section 33).

All of the Crown Zellerbach wastes are discharged to the Strait of Juan de Fuca where adequate dilution is available. However, the wastes from the Rayonier and Fibreboard Products mills are discharged into Port Angeles Harbor where a total flushing time exceeding four days is indicated by our data. To further illustrate the toxic effects of the waste streams shown in Table 37-4, the amounts of dilution water required to reduce the toxicity of each to non-harmful levels (i.e., no larval abnormality) were computed and are shown in Table 37-5. On the

TABLE 37-4. Dilution ratios and SWL concentrations of waste dilutions which produce 0, 20, 50, and 100% abnormal oyster larvae. The wastes were collected from sources in the Port Angeles area.

Waste Stream	No Abnormality		20% Abnormality		50% Abnormality		100% Abnormality		Mean Percent Abnormal in Laboratory Controls
	SWL (ppm)	Dilution Ratio	SWL (ppm)	Dilution Ratio	SWL (ppm)	Dilution Ratio	SWL (ppm)	Dilution Ratio	
Rayonier									
Main sewer	6	1:10,000	13	1:4,540	21	1:3,000	68	1:1,000	0.41
Screen room	1	1:2,000	5	1:145	8	1:112	89	1:20	0.41
Barker	0	1:100	3	1:61	7	1:46	15	1:20	0.41
Fibreboard Products									
Composite sewer	5	1:10,000	15	1:2,100	20	1:1,650	33	1:1,000	0.40
Crown-Zellerbach									
Bleach wash	0	1:2,000	1	1:560	2	1:370	4	1:100	0.58
Main mill paper machine	0	1:1,000	1	1:59	2	1:39	6	1:10	0.58
Groundwood screenings	4	1:200	9	1:62	13	1:46	30	1:20	0.58
Groundwood refiner	15	1:100	24	1:59	32	1:43	65	1:20	0.58

basis of this study, it is calculated that over 270 billion gallons per day of unpolluted dilution water would be required in Port Angeles Harbor to dilute these wastes to that degree.

TABLE 37-5. Dilution water required to reduce the toxicity of Port Angeles area wastes to zero (have no effect on oyster larva development).

Waste Stream	Waste Flow* (mgd)	Dilution Water Required for no Abnormality (cfs)**
Rayonier		
Main sewer	20.90	323,370
Screen room	9.00	27,850
Barker	0.70	110
Fibreboard Products		
Composite sewer	4.60	71,170
Crown Zellerbach		
Bleach wash	2.92	9,040
Main mill paper machine	5.90	9,130
Groundwood screenings	0.91	280
Groundwood refiner	1.34	210

* Average flow rate, in millions of gallons per day, for period when samples were collected.

** Cubic feet per second (one cfs is equal to 643,317 gallons per day).

DISCUSSION

Although no commercial production of oysters is known for the Port Angeles area, an appreciable sport and commercial clam fishery is found along the beaches toward and past Dungeness Spit where suitable bottom materials occur. As noted in Section 10, all of the bivalve mollusk larvae and adults tested thus far show about the same response to similar levels of SWL, so the results of this study reveal probable damage to the shellfishes of the Port Angeles area.

Since the circulation in the Port Angeles area is a counter-clockwise eddy system with pulpmill wastes being dispersed eastward alongshore toward Dungeness Spit, treatment of these wastes is necessary for shellfish protection. Attention is called to the tremendous amounts of dilution water required to reduce the toxicity of these wastes to non-harmful levels (Table 37-5) and the rather slow flushing of the wastes following complete cessation of production (see page 436).

38. BACTERIOLOGICAL STUDIES

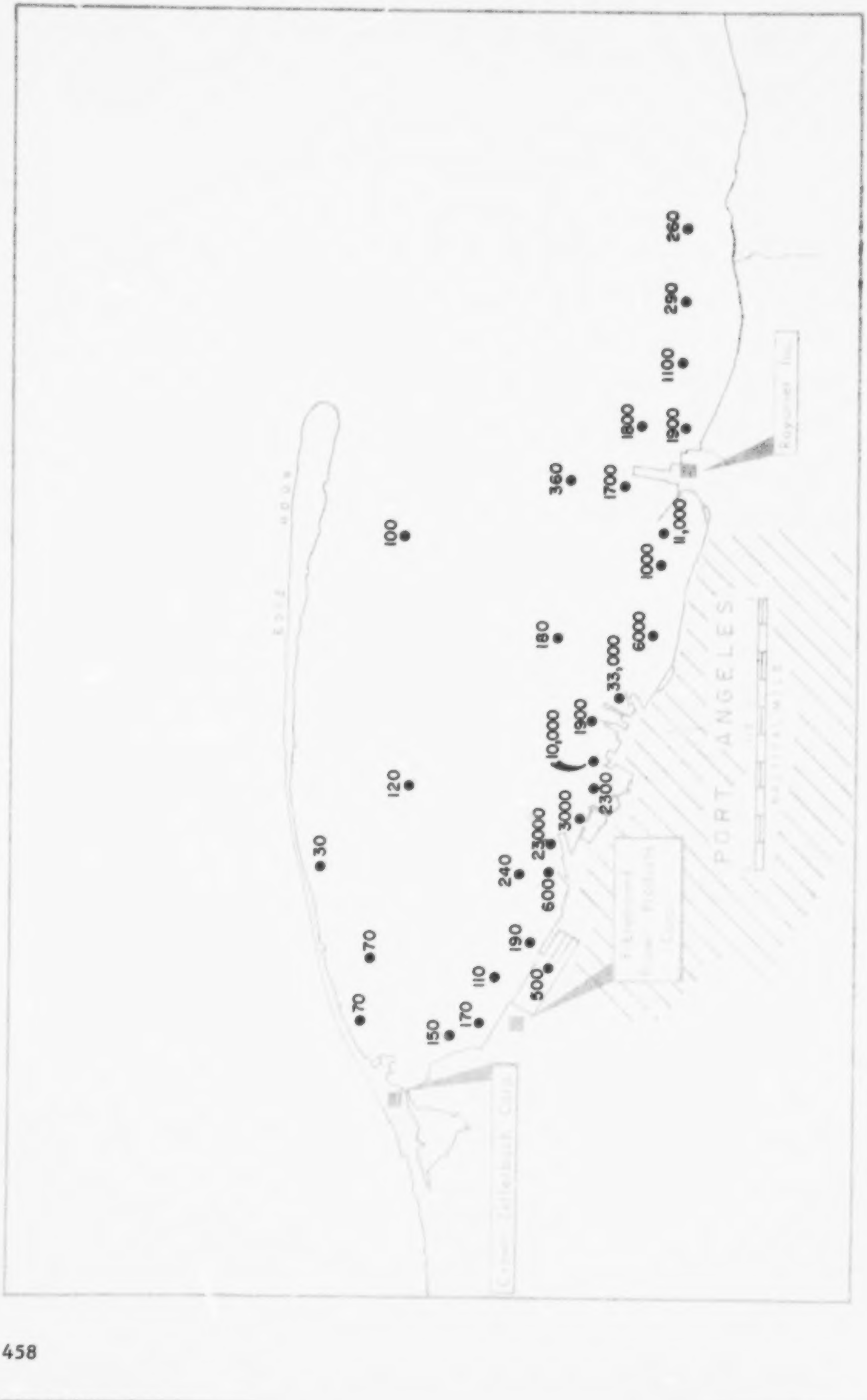
The waters of Port Angeles Harbor are used for commercial and sport fishing, log rafting and sorting activities, towboat operations, pleasure boating, sport diving, and shoreline recreation. Water contact incidental to these uses makes the bacterial quality of these waters important. Sources of bacterial pollution within the Harbor include the discharge of untreated wastes from the several City of Port Angeles sewer outfalls (see Figure 32-1 for outfall locations), waterfront industries and properties, and boats. Studies were conducted by the Project to assess the extent of bacterial pollution in Port Angeles Harbor.

STUDIES

The Project conducted three bacteriological surveys in Port Angeles Harbor, one in September 1964 and two in August 1966. On each survey, concentrations of total coliforms and fecal streptococci were determined for surface samples taken at each of 28 sampling stations located within the Harbor (Figure 38-1). Associated surface water temperature and salinity also were measured at each station.

METHODS

Sample collection, handling, and analyses during the Project bacteriological studies of Port Angeles Harbor were the same as those described in Section 15.



260
290
1100
1900
1800
360
1700
11,000
1000
100
6000
180
33,000
1900
10,000
2300
3000
120
23,000
600
240
30
190
70
110
500
170
70
150
PORT ANGELES
EDIZ HOOK
Rayonier Inc.
Crown Zellerbach Corp.

FIGURE 38-1. Bacteriological sampling stations and average concentrations of total coliforms in Port Angeles; data from Project studies, 1964 and 1966.

RESULTS

The average concentration of total coliforms observed at each station over the three surveys is shown in Figure 38-1. Note that the average bacterial count exceeds 1,000 organisms/100 ml along at least two of the City's three miles of waterfront. A comparison of the bacterial distribution (Figure 38-1) with the locations of the City of Port Angeles' sewer outfalls (see Figure 32-1) shows that the highest bacterial counts are found definitely associated with sewer outfall locations.

DISCUSSION

Bacterial standards proposed by the Washington Pollution Control Commission for these waters require that average concentrations of total coliforms be less than 1,000/100 ml for water contact use. The Project's studies show that this criterion is severely violated along a two-mile section of the City of Port Angeles waterfront. Thus, this area is contaminated and should not be used for water contact activities.

The principal cause of bacterial pollution in Port Angeles Harbor is the shoreline discharge of raw sewage from the City of Port Angeles. These wastes, collectively estimated at 2.2 mgd (see Section 33), also contribute substantial BOD and solids loadings to the Harbor, resulting in local water quality degradation and solids accumulations. Preliminary design of a waste collection system and primary treatment facility was developed for the City by an engineering firm in 1966 but it has not progressed to construction; thus bacterial contamination and sewage pollution of the Harbor persist. This continuing discharge of raw wastes by the City produces an unreasonable public health hazard and nuisance condition which should be immediately abated.

39. SUMMARY

There are two principal sources of pulp mill wastes in the Port Angeles area; the Fibreboard Paper Products Corp. pulp and board mill located on the south shore at the inner end of Port Angeles Harbor, and the Rayonier Incorporated pulp mill located on the south shore at the Harbor entrance. Both mills discharge process wastes directly to Harbor surface waters. Of the two mills, Rayonier Incorporated is by far the more significant waste source, contributing about 92 percent of the combined discharges of SWL, COD, BOD_5, and total solids. Wastes from these mills are found throughout Port Angeles Harbor, particularly in the southern portion, and eastward nearshore as far as Dungeness Spit, some 12 miles from the Harbor entrance.

The Crown Zellerbach Corp. pulp (mechanical) and paper products mill, located at the inner end of the Harbor, discharges its wastes directly to the Strait of Juan de Fuca. Except for some transient local collection near the outfall these wastes generally are dispersed seaward by Strait currents and, thus, are not prominent within the main Port Angeles study area. However, during past years the now-discontinued Crown Zellerbach discharge of high solids wastes into Port Angeles Harbor substantially contributed to a large sludge bed still present at the inner end of the Harbor.

Project studies have shown that these wastes are damaging to marine life in the Port Angeles study area. The damages are of two types: (1) acute damages, occurring within the Harbor adjacent to each mill and mainly associated with the concentrated sulfite waste liquors and settleable solids in the mill effluents, and (2) chronic damages, occurring throughout the study area and associated with dilute concentrations of sulfite waste liquors.

Within Port Angeles Harbor, waste discharges from Fibreboard and Rayonier produce high waste concentrations, sludge deposits and attendant water quality degradation surrounding each mill. Also, the sludge deposit formed by past Crown Zellerbach discharges continues to seriously degrade water quality adjacent to that mill. These conditions are incompatible with marine life and interfere with other legitimate water uses. Specifically, mill wastes discharged into the Harbor have been shown to:

1. Injure juvenile salmon migrating through the Harbor.
2. Form sludge deposits which damage benthic organisms, produce harmful water quality degradation, and result in general aesthetically unattractive conditions.

It is imperative that wastes from all three mills be treated for removal of settleable solids prior to discharge.

Of even greater importance to marine life in the study area is the presence of dilute sulfite waste liquor (from Fibreboard and Rayonier mills) in waters throughout the Port Angeles study area. Such wastes, even in concentrations as low as 5 to 15 ppm, have been found harmful to immature forms of fish and shellfish. Project bioassay studies in the Port Angeles area show that extensive damages occur to oyster larva at waste levels found in surface waters of the Harbor and eastward alongshore to Dungeness Spit. On the basis of other bioassay studies reported for Bellingham and Everett (Parts I and III, this report), these waste levels also are damaging to a wide variety of important marine life found in the affected portion of the Port Angeles study area, including crabs, clams, sole, cod, anchovy, herring and smelt.

The waste assimilation capacity of the Port Angeles study area is seriously limited by the presence of a large, slow moving, predominantly anti-clockwise, eddy circulation of water between Port Angeles Harbor and Dungeness Spit. This eddy tends to confine Fibreboard and Rayonier mill wastes to shallower waters alongshore before eventually dispersing them to the Strait of Juan de Fuca. This results in harmful concentrations of SWL throughout the eddy. Inadequate depth precludes relocation of the mill outfalls (to any reasonable site) within the eddy system to secure acceptable waste dilution. This is particularly true of the Rayonier mill because of its large volume of waste discharge. Therefore, to prevent further damage to the marine resources of the Port Angeles study area, it will be necessary to significantly reduce sulfite waste liquors at the source. Minimum protection of the marine biota during their most sensitive life stages requires that sulfite waste liquor concentration not exceed 10 ppm within 50 feet of the surface depth beyond an initial waste dispersion zone. The initial waste dispersion zone is defined as the area within Port Angeles Harbor bounded on the east by an arc formed by that radius originating from Rayonier Incorporated and extending to the eastward end of Ediz Hook, swung to the east.

The Pen-Ply plywood mill discharges a small amount of glue wastes to the Harbor, but no significant adverse effects on water quality were observed.

The City of Port Angeles discharges all of its domestic wastes untreated into Port Angeles Harbor. As a result, more than two miles of the City's waterfront is bacterially contaminated for water-contact use. Also, this waste source contributes substantial BOD and settleable solids loading to the Harbor. Protection of those persons engaged in contact use of these waters requires immediate abatement of this pollution.

LITERATURE CITED

Anonymous.

1962a. Pollution of interstate waters; Puget Sound, Strait of Juan de Foca, and their tributaries and estuaries; State of Washington. Transcript of conference, first session, Jan. 16-17, 1962, Olympia, Wash. U. S. Public Health Service, Portland, Ore. 3 vol. (432 p. append.)

A.P.H.A.

1962. Standard methods for the examination of water and wastewater. 11th Ed. Amer. Publ. Health Assoc., New York. 626 p.

1965. Standard methods for the examination of water and wastewater, 12th Ed. Amer. Publ. Health Assoc., New York. 769 p.

Barnes, C. A., E. E. Collias, V. F. Felicetta, O. Goldschmid, B. F. Hrutfiord, A. Livingston, J. L. McCarthy, G. L. Toombs, M. Waldichuk, and R. Westley.

1963. A standardized Pearl-Benson, or nitroso, method recommended for estimation of spent sulfite liquor or sulfite waste liquor concentration in waters. TAPPI 46 (6): 347-351.

Cahn, A. R.

1950. Oyster culture in Japan. U. S. Fish & Wildlife Serv. Fish. Leafl. 383. 80 p.

Charnell, H. V.

1958. Water quality, Port Angeles Harbor, 1956-1958. Rayonier, Inc. 5 p.

Collias, E. E., and C. Barnes.

1962. An oceanographic survey of the Bellingham-Samish Bay system: Vol. I, physical and chemical data. Univ. Wash. Dept. Ocean. Special Report No. 32. 138 p.

Crutchfield, James A.

1963. An economic analysis of certain aspects of in-place uses of Puget Sound waters. Ms. 74 p., sev. tbls., appendices.

Farmer, Harlow G., and M. Rattray, Jr.

1963. A model study of the steady-state salinity distribution in Puget Sound. Univ. Wash. Dept. Ocean., Tech. Report No. 85. 33 p.

Gunter, Gordon, and Jack E. McKee.

1960. On oysters and sulphite waste liquors. Washington State Pollution Control Commission.

Herlinveaux, R. H., and J. P. Tully.

1961. Some oceanographic features of Juan de Fuca Strait. J. Fish. Res. Bd. Canada 18(6) 1027-1071.

McKee, Jack Edward, and Harold W. Wolf.

1963. Water quality criteria, 2nd edition. Calif. State Water Quality Control Bd. 548 p.

McKinley, W., D. C. Brooks, and R. E. Westley.

1959. Measurements of water transport through Swinomish Slough, Washington. Wash. Dept. Fish., Fisheries Research Papers 2 (2) 84-87.

Nelson, Norton.

1944. A photometric adaption of the Somogyi method for the determination of glucose. J. Biol. Chem., Vol. 153, 375 p.

Oppenheimer, Carl H.

1955. The effect of marine bacteria on the development and hatching of pelagic fish eggs, and the control of such bacteria by antibiotics. Copeia 1: 43-49.

Orlob, Gerald T., Donald R. Peterson, and Kenneth R. Jones.

1951. A reinvestigation of pollution in Port Gardner Bay and the Snohomish River. Wash. Pollution Control Comm., Tech. Bull. 11. 11 p.

Ott, Charles, Alfred Livingston, and Al Mills.

1961. Water quality survey, Port Angeles. Ms. 6 p., sev. tbls.

Paulik, Gerald J.

1963. Larval bioassay interim report to the U. S. Public Health Service. Ms. 14 p., sev. tbls.

1964. Larval bioassay interim report to the U. S. Public Health Service. Ms. 12 p., sev. tbls. & figs.

1965a. Preliminary report on larval bioassay data collected during pulp mill strike period in Northern Puget Sound. Ms. 5 p., 3 tbls.

1965b. Addendum to preliminary report of larval bioassay data collected during pulp mill strike period in Northern Puget Sound. Ms. 3 p.

1965c. Adult oyster mortality report, 1964-65 experiments (with addendum). Ms. 16 p., 2 tbls., 7 figs.

1966a. Final statistical summary report on larval bioassay study. Ms. 32 p., 10 tbls., 9 figs.

1966b. Juvenile oyster mortality study. Ms. 6 p., 2 tbls.

1966c. Growth of juvenile oysters. Ms. 6 p., 4 tbls.

1966d. Condition factor indices of adult oysters in Bellingham Bay, 1963-66. Ms. 9 p., 5 tbls., 1 fig.

Paulik, Gerald J. (con't.)

1966e. Mortalities of adult oysters in Bellingham Bay, 1965-66. Ms. 10 p., 8 tbls., 2 figs.

1967. Growth of adult oysters. Ms (in preparation).

Peterson, Donald R., and Charles V. Gibbs.

1957. An investigation of pollution in the vicinity of Port Angeles. Wash. Pollution Control Comm., Tech. Bull. 23. 35 p.

Pine, R. and T. Clemetson.

1961. Bellingham Bay and Port Angeles diving observations. Ms. 2 p.

Polikarpov, G. G., and V. N. Ivanov.

1961. Injurious effect of strontium-90 -- yttrium-90 on early development of mullet, Wrasse, horse mackeral, and anchovy. Doklady Biol. Sciences Section 144 (1-6): 459-654.

Quayle, D. B.

1951. The seasonal growth of the Pacific oyster (ostrea gigas) in Ladysmith Harbour. Brit. Columb. Prov. Dept. Fish. Rept. (1950), p 85-90.

Rattray, Maurice, Jr.; and John H. Lincoln.

1955. Operating characteristics of an oceanographic model of Puget Sound. Trans. Amer. Geophysical Union, 36(2): 251-261.

Robison, Robert, Dale Ward, and Arthur Palmen.

1962. 1961 fisheries statistical report. Wash. State Dept. Fish. 199 p.

Steele, E. N.

1964. The immigrant oyster (ostrea gigas) now known as the Pacific oyster. Warren's Quick Print, Olympia, Washington. 179 p.

Stein, J. E., J. G. Denison, and G. W. Isaac.

1963. An oceanographic survey of Port Angeles Harbor. Ore. State Univ. Engineering Experiment Station, Circ. 29., p. 172-202.

Sternberg, R. W.

1961. Recent sediments in Bellingham Bay, Washington. MS Thesis. Univ. Wash. Dept. Oceanog. 183 p.

Strickland, J. D. H.

1960. Measuring the productivity of marine phytoplankton. Fish. Res. Bd. Canada, Bull. 122. 172 p.

Strickland, J. D. H., and T. R. Parsons.

1960. A manual of seawater analysis. Fish. Res. Bd. Canada, Bull. 125. 185 p.

Tyler, Richard W.

1963. Distributor and migration of young salmon in Everett Harbor, 1962. Fish. Res. Inst. Univ. Washington. Ms. 26 p.

1964. Distribution and migration of young salmon in Bellingham Bay, Washington. Fish. Res. Inst. Univ. Washington, Circ. 212. 26 p.

1965. Distribution and migration of young salmon in Everett Harbor relative to water quality, 1963 and 1964. Fish. Res. Inst. Univ. Washington. Ms. 84 p.

U. S. C. & G. S.

1966. Tidal current tables, 1966, Pacific Coast of North America and Asia. U. S. Government Printing Office, Washington, D. C. 254 p.

Wagner, R. A. and E. Ice.

1958. Guemes Channel and Padillo Bay float and circulation studies. Wash. Pollution Control Comm. 77 p.

Wagner, R. A., C. Ziebell and A. Livingston.

1957. An investigation of pollution in north Puget Sound. Wash. Pollution Control Comm., Tech. Bull. 22. 27 p.

Ward, Dale, Robert Robison, and Arthur Palmen.

1963. 1962 fisheries statistical report, p. 123-211. In: Department of Fisheries 72nd annual report. Wash. State Dept. Fish.

1964. 1963 fisheries statistical report, p. 125-216. In: Department of Fisheries 73rd annual report. Wash. State Dept. Fish.

Washington Department of Fisheries.

1960. Sulphite waste liquor, p. 51-82. In: Toxic effects of organic and unorganic pollutants on young salmon and trout. Wash. Dept. Fish., Research Bull. 5.

Washington Pollution Control Commission.

1958. Water quality data, north Sound area. Wash. Pollution Control Comm., Water Quality Data Bull. 58-3. 23 p., sev. tbls. & figs.

Westley, Ronald E.

1957. Physical and chemical data, north Puget Sound hydrographic trips, 1956 and 1957. Wash. Dept. Fish. Hydrographic Data, Vol. II (6). 21 p. & append.

1960. Observations on physical and chemical water characteristics of Bellingham and Samish Bays, p. 59-80. In: Reports on sulfite waste liquor in a marine environment and its effect on oyster larvae. Wash. Dept. Fish., Res. Bull. 6.

Westley, Ronald E. (con't.)

1961. Selection and evaluation of a method for quantitative measurement of oyster condition. Proc. Natl. Shellfisheries Assoc., 50: 145-149.

Westley, Ronald E., and M. Tarr.

1959. Physical and chemical data, north Puget Sound hydrographic trips, 1958. Wash. Dept. Fish. Hydrographic Data, Vol. III (1). 46 p. & append.

1960. Physical and chemical data, north Puget Sound hydrographic trips, 1959. Wash. Dept. Fish. Hydrographic Data, Vol. III (2). 22 p. & append.

Williams, R. W., E. M. Mains, W. E. Eldridge, and J. E. Lasater.

1953. Toxic effects of sulphite waste liquor on young salmon. Wash. Dept. Fish., Research Bull. 1. 111 p.

Woelke, Charles E.

1959. Natural setting of Pacific oysters in Washington waters in 1958. Wash. State Dept. Fish. (processed). 6 p.

1961a. Growth of the Pacific oyster, *crassostrea gigas*, in the waters of Washington State. Proc. Natl. Shellfisheries Assoc., 50: 133-143.

1961b. Bioassay--the bivalve larvae tool, p. 113-123. *In*: Proc. 10th Pac. N.W. Symp. on Water Poll. Res., Portland, Ore.

Woelke, Charles E. (con't.)

1965 (unpublished to be added) Ref. p. 146.